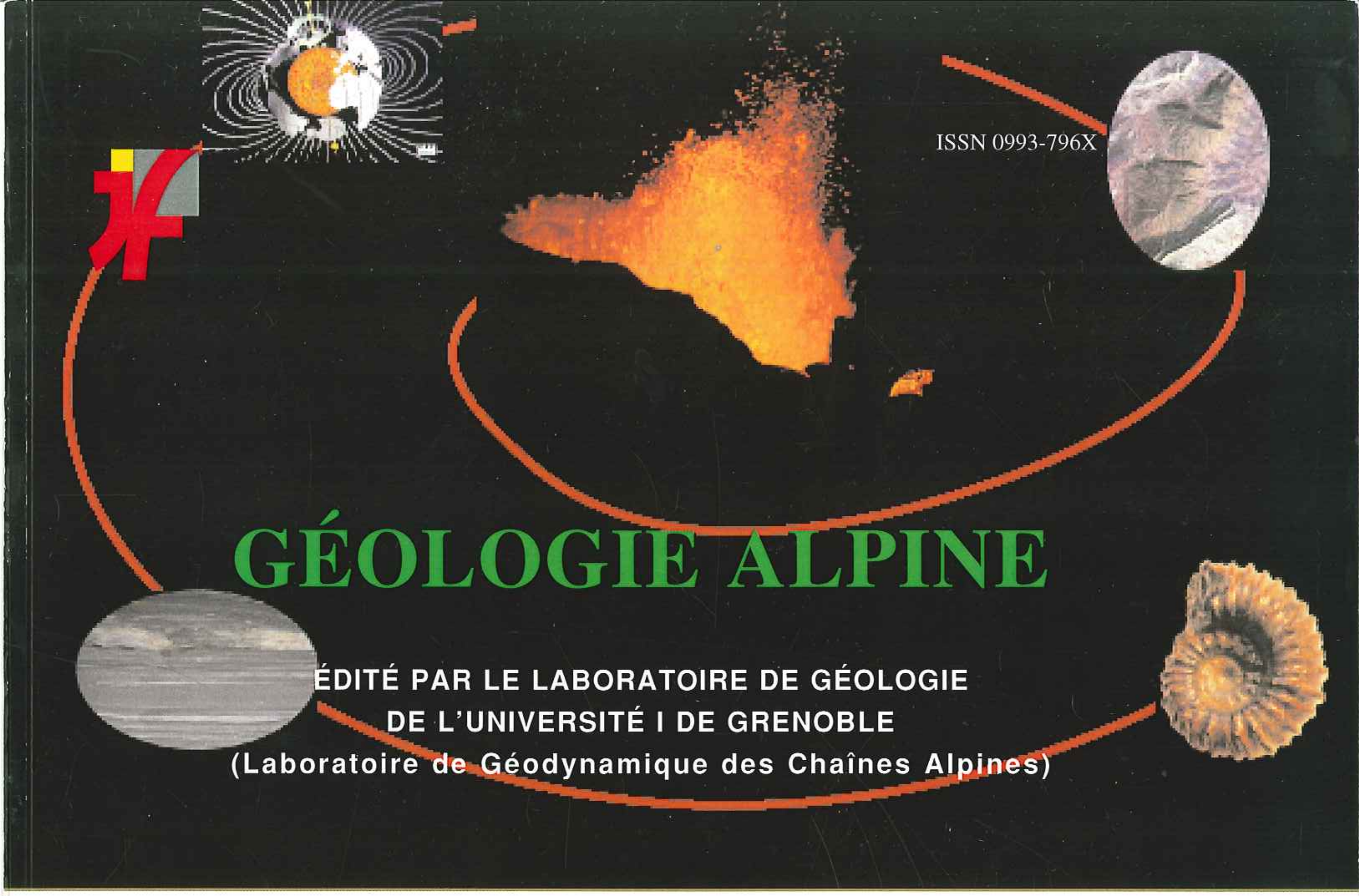
Global events during the quiet aptian-turonian superchron : [symposium], Grenoble, 21-23 avril 2005

Annie Arnaud Vanneau, Nicholas Arndt, Ihsen Zghal



ISSN 0993-796X

GÉOLOGIE ALPINE

ÉDITÉ PAR LE LABORATOIRE DE GÉOLOGIE
DE L'UNIVERSITÉ I DE GRENOBLE
(Laboratoire de Géodynamique des Chaînes Alpines)

SÉRIE SPÉCIALE «COLLOQUES ET EXCURSIONS» N° 6

GLOBAL EVENTS DURING THE QUIET APTIAN-TURONIAN SUPERCHRON

Grenoble 21-23 avril 2005

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UNIVERSITE JOSEPH FOURIER
SCIENCES. TECHNOLOGIE. MEDECINE

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ORAL PRESENTATIONS

THE MAGMATIC ROCKS OUTCROPPING THE CRETACEOUS OF THE KAIROUAN REGION (CENTRAL TUNISIA): THE SETTING UP GEODYNAMIC FRAME

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The Cretaceous volcanism of the Kairouan region in the centre of Tunisia, and precisely at the level of the North- South axis (s.s) is represented in Jebels Haouareb, Jediri, Batene and Botnane El Homor, by a spacial association with materials composed mainly of basalt (fig 1).

The volcanic rocks of Jebel Haouareb were discovered by Abbes and Smaoui (1981), and were described as basaltic lava flows altering pebbles of a different nature.

The ground cutting shows from basis to summit:
- A series of sandestone-like Aptian-age dolomites.
- Limestones with sea-urchin surmounted by entrochal limestones, then by marly-calcareous.
- A light green, sometimes reddish volcano-sedimentary formation which dates back to the Turonian-Coniacian.
- A breach altering the volcanic material.
- Dolomitic limestones.
- A series of marly calcareous of the Coniacian.

The outcrop of Jebel Jediri rocks was also described for the first time by Abbes and Smaoui (1981). It consists of a basaltic rock stuck as a thrust slice between the mass of Aptian limestones and the subjacent Meloussi formation . This outcrop is made up of a lentil stretching about a hundred metres. It consists of an altered and friable rock colored from dark green to rust green. This rock is crossed by numerous ledges of whitish calcite.

The volcanic rocks of Jebel Batene are in massives form colored from green to grey green. It is Castany (1952) who described them as ophites and attributed them to Triassic. Later, Bajanik (1971) related them to Cretaceous magmatic rocks because they are in contact with the Campanian and theAlbian-Aptian.

The volcanic rocks of Jebel Botnane El Homor are in the form of a level which is about 1 km long and 10 meters wide.

This volcanic rock level is surrounded by a carbonatied formation of the Turonian age and by sandestones of the Albian- Aptian. On the ground, this rock is dark green, sometimes light red, quite altered and jointed with a calcite filling.

The detailed petrographic study of these volcanic rocks shows that they contain the same mineralogic assemblage with some difference.

The observation of thin plats cut at the level of the volcanic rocks coming from the four outcrops already mentioned, under polarization microscope, shows that the minerals form a mineralogic assemblage of plagioclases, olivines transformed in iddingsite, pyroxenes, epidotes, calcite, dark minerals and clayey minerals. All these minerals bathe in a microlitic matrix formed by plagioclase microlites. These results confirm that we are dealing with basaltic rocks frequently altered.

The X-ray mineralogic analyses on total rock powder, confirm the microscopic observations, that is the presence of plagioclases, olivines, pyroxenes, epidotes calcite and oxydes (fig 2).

The oriented aggregates prepared from the same samples show that they consist of clayey minerals of a: chlorite type that appears mainly at 14 Å at the level of the normal clay slide and the treated clay slide (warmed to 500° C during 4 hours and inflated with ethylene-glycol); illite type that appears mainly at 10 Å at the level of the three clay slides and smectite type that appears mainly at 15 Å for the normal clay slide , at 10 Å after heating and at 17 Å after inflating with ethylene- glycol (fig 3).

During the Cretaceous, the distension spreads at the level of the Tunisian margin; this permitted the setting up of several plicative and brittle structures along the different branches N-S, NE-SW and NW-SE. These different structures permit either , the magmatic liquid ascent at earthly surface by the volcanic manifestations essentially basic from the Aptian at lower Campanian. The important episode is situated at the Cenomanian (Abbes, 2004). Or the contribution at the surface of magmatic rocks of basalt type by the presence of deep tectonic by the antetriasic socle cutting according to a reghmatic accidents network of the N 60-70, N-S and N160-180 directions (Abbes, 2004).

With regard to the studied outcrops, the major accident is the N-S flexure (attached to the hercynian socle which occurred in the Turono-Coniacian distensive phase, which facilitates the ascent of the basaltic rock to the surface.

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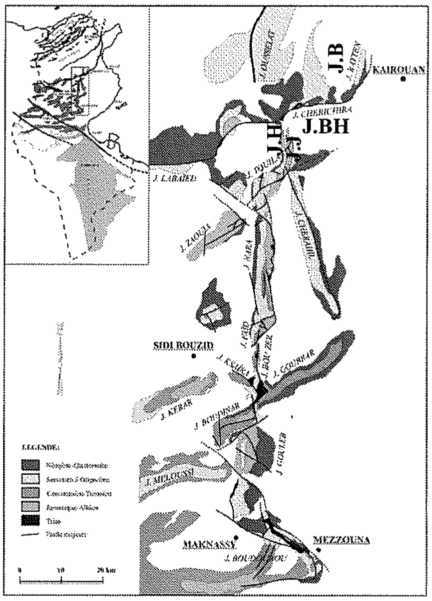
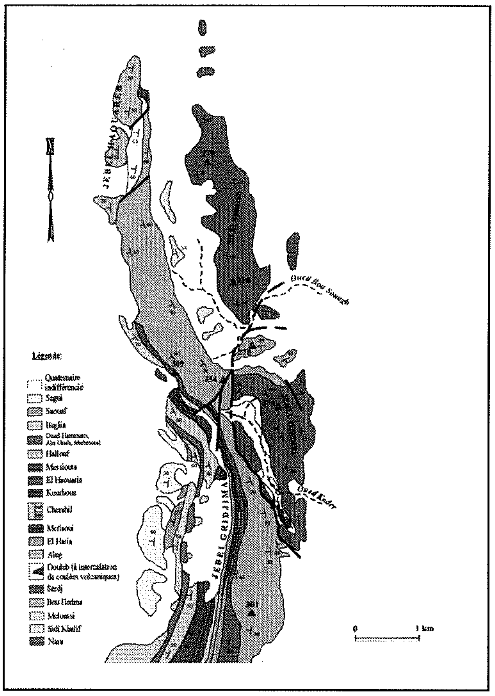
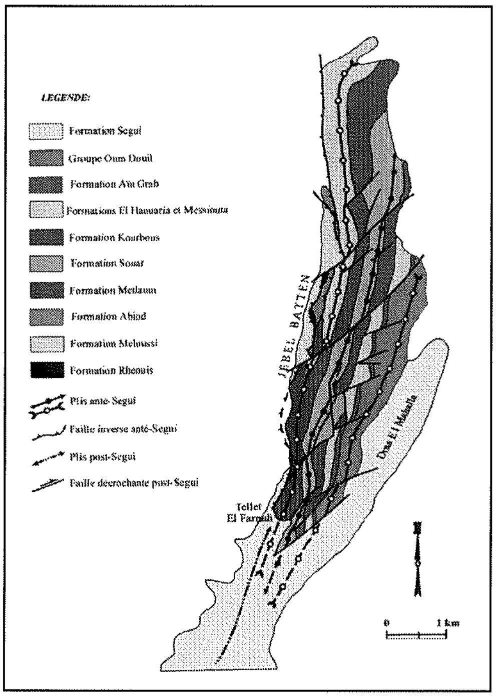
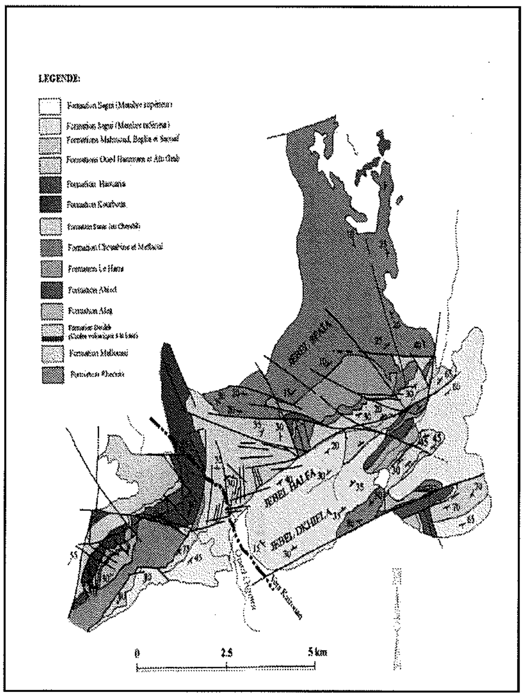




Localization of volcanic rocks at the level of Jebels Haouareb and Jediri (Abbès, 2004)



Localization of volcanic rocks at the level of Jebel Jebel Batène (Abbès, 2004)



Localization of volcanic rocks at the level of Jebel Jebel Botnane El Homor (Abbès, 2004)

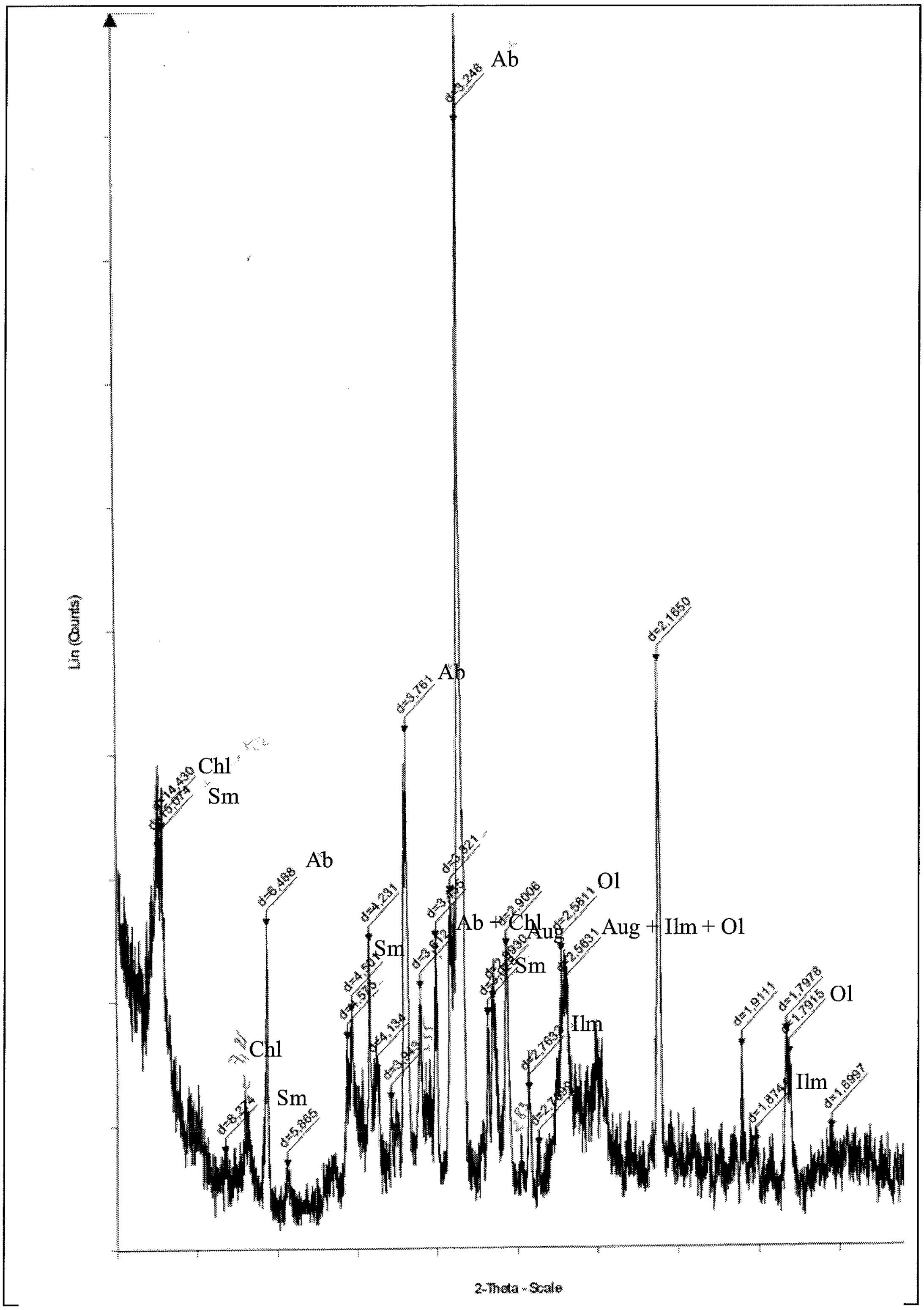


Figure 2 : X-ray diffraction profiles on the clay size fraction of Jebel Batene (Aboub, 2004)

Ab : albite, Aug : augite, Cal : calcite, Chl : chlorite, Ilm : ilménite, Ol : olivine, Sm : smectite.

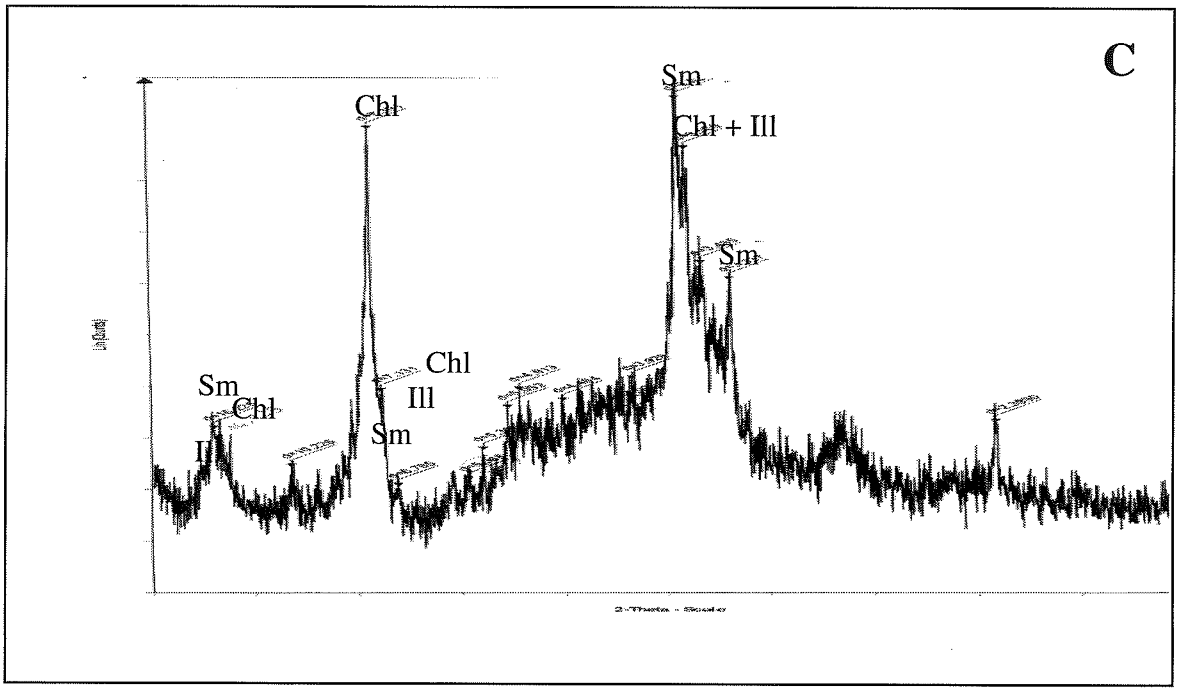


Figure 3c: X-ray diffraction profiles on the clay size fraction of Jebel Batene (Aboub, 2004)
C: Ethylene glycol solvated preparation Chl : chlorite, Ill : illite, Sm : smectite

The Cenomanian-Turonian global events : a review

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The Cenomanien-Turonian oceanic anoxic event is worlwide associated with a great marine transgression, the coeval deposition of organic rich sediments and a significant □^{13}C positive excursion. The Cenomanian-Turonian boundary transition (CTB) marks a major greenhouse warming accompanied by global ocean anoxia that was detrimental to marine benthic and planktic organisms. The mid-Cretaceous earth is often referred to as a 'greenhouse' world, i.e.characterised by high atmospheric CO2 levels. However, recent findings indicate that a sharp drop in atmospheric CO2 concentrations occurred during the Cenomanian/Turonian (C/T) oceanic anoxic event (OAE). This was due to the burial of immense amounts of organic carbon in marine sediments under anoxic conditions in the oceans and shelf seas. Subsequently, CO2 levels increased again, making the C/T OAE a natural climatic experiment in Earth history relevant for the present-day situation of increasing CO2 levels. However, the causes and consequences of the C/T events are still poorly understood and may relate to tectonic events, volcanism, sea-level changes, climate and subsequent weathering and changes in palaeoproductivity. the used herein multiproxies approach is focused on stable isotopes, bulk and clay mineralogy, phosphorus coupled to organic carbon accumulation and other paleoproductivity indicators, quantitative micropaleontology in order to assess the change in weathering processes due to greenhouse conditions and its influence on paleoproductivity and/or organic carbon preservation. For better correlations of the timing and tempo of the CTB events, high resolution biostratigraphic data is needed, based on planktic foraminifera and the subdivision of *Whiteinella archeocretacea* zone into three subzones.

The Pueblo, Colorado stratotype section has been analyzed based on stable isotopes, organic and mineralogical contents and faunal turnover in planktic foraminifera. Carbon isotope compositions measured from *Hedbergella* species in marls, shales and bentonites show similar trends to those at Eastbourne and elsewhere. A rapid 2-2.5‰ δ^{13}C positive excursion begins at the top of the Hartland Shale Member or 50 cm below the base of the Bridge Creek (limestone bed 63), and reaches maximum values about 1 m above the base of the Bridge Creek (limestone beds 67-69). The excursion continues through the basal 5 m of the lower Bridge Creek Limestone Member and decreases only slightly in the early Turonian (*H. helvetica* zone) near the top of the section. Superimposed on the lower half of the δ^{13}C excursion are cyclic fluctuations varying between 0.3 to 0.9‰ that appear to be related to rock type, productivity and oxygenation of the water column, as suggested by covariant abundance fluctuations in low oxygen tolerant heterohelicids and surface dwelling hedbergellids. δ^{18}O ratios of *Hedbergella* show a wide range of unusually light values from –12 to –6.5‰, similar to those previously observed in bulk rock carbonates. The overall trend is towards heavier values in the lower part of the Harland Shale and the Bridge Creek Limestone and lighter values during *Rotalipora cushmani* zone, suggesting transgressive and regressive cycles respectively. Superimposed over this trend are cyclic variations in δ^{18}O values that may represent variations in the upper water column related to periodic freshwater influx (lightest values) to the Western Interior seaway. This is also indicated by the HI/OI index of organic carbon that suggests a change in organic matter composition correlative with fresh water influx. In addition, correlative increases in quartz and phyllosilicates (mainly kaolinite) indicate increased detrital input during fresh water influx. Correlative cyclic variations are also observed in planktic foraminiferal species poppulations with peak abundances of *Hedbergella planispira* but decreased *Heterohelix reussi* and *H. moremani* during fresh water influx.

Correlation with european sections, based on our multistratigrapical approach, indicate sea-level fluctuations during major regression and transgression phases. At Eastbourne (England) and Vergons (Vocontian Through, France), major marine regression accompanied the ∂^{13}C excursion near the top of the R. cushmani zone (Plenus Marls Bed 1 to 4). followed by the onset of a marine transgression that continued through the W. archaeocretacea zone. At Cassis, the CTBE is characterized by higher accumulation rate probably due to higher terrigenous influx. The *W. archeocretacea* zone is therefore 50m thick. The ∂13C excursion is consequently very expanded compared to other sections located in Spain, Tunisia and especially to the GSSP section of Pueblo (USA). These data
are essential to precise the nature and timing of the faunal changes and how these events are correlated with changes in clay-minerals, P, C and CaCO3 fluxes (productivity *versus* preservation), in order to precise climatic and weathering conditions which prevailed during the CTB events.

Large Igneous Provinces: their Characteristics, Origin and Effect on the Environment

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A Large Igneous Province (LIP) is a large volume of mainly mafic rock that was emplaced was generated and emplaced in a relatively short period of time by processes distinct from normal seafloor spreading and subduction-related magmatism. LIPs form both on the continents, as flood volcanic provinces, and in ocean basins, as oceanic plateaus. The biggest examples are enormous: the Siberian flood volcanic plateau contains $1x10^6$ km^3 of mafic rock; the Ontong Java oceanic plateau covers an area the size of western Europe with up to 30 km of lavas and intrusions. Although mafic rocks, mainly evolved tholeiitic basalt, dominate the upper portions of most plateaus, some plateus (Ethiopia, Etendeka) contain up to 20% of felsic pyroclastics. LIPs range in age from about 17 Ma (the Columbia River basalts are the youngest and no LIP is currently forming) to at least 2.7 Ga. Throughout the Mesozoic and Cenozoic, a LIP erupted every 20-30 Ma.

These short, violent and enormous volcanic eruptions had profound effects on the environment. Eruption of a single flood basalt releases vast amounts of noxious gas and volcanic ash into the atmosphere, creating conditions that resemble a "nuclear winter". Our best reference is the eruption of the Laki flow in Iceland in 1783-84, which caused the death of most of Iceland's sheep population (mainly from fluorine poisoning) crop failure and famine, and abnormally cold summers and winters throughout the world. The Laki flow is only 20-30% the size of a single continental flood basalt; the consequences for the atmosphere, hydrosphere and biosphere of the eruption of several hundred such flows over a period of 1-2 million years should have been catastrophic. Added to these effects are those of felsic pyroclastic eruptions, which ejected gas and ash high into the atmosphere. A probable climatic cycle associated with a flood-volcanic event is a short period of cooling and interuption of solar radiation during the period of eruption, an intermediate period of warming due to the release of greenhouse gases, and a subsequent period of cooling as CO_2 is absorbed during the alteration of the volcanic rocks.

The consequences of submarine emplacement of an oceanic plateau should be less dramatic because ocean waters would prevented direct ejection of volcanic products into the atmosphere. However, hydrothermal interaction of seawater with solid basalt, and of basaltic magma with sedimentary rocks, would have had other effects. The release of vast volumes reduced hydrothermal fluids led to anoxic conditions throughout the oceans, and contact metamorphism of sediments rich in organic matter by magma flowing through shallow-level intrusions released large quantities of CO_2, CH_4 and other greenhouse gases into the oceans and atmosphere.

Impact of a global oceanic event on evolution of plaktic foraminifera: a major turnover during the C/T boundary interval.

Michèle CARON

In the approximately 1 million-year interval encompassing the events associated with the C/T boundary interval, changes in planktic foraminiferal assemblages (i.e., relative abundance and species diversity) reflect paleoenvironmental perturbations. At both Pueblo and wadi Bahloul sections, planktic foraminifera dominate the microfossil assemblages, as observed in thin sections and washed residues. Comparison between planktic foraminifera ranges and the rich record of ammonites provides an important framework for interbasinal correlations. The whole of planktic foraminiferal event which occurred at this time can be identified as a major global turnover.

The turnover structure *(figure)*

Before the turnover event, high diversity prevailed in the trochospiral keeled species (belonging to the genera *Rotalipora*, *Dicarinella*, *Praeglobotruncana* and *Whiteinella* pro parte) that were deep and intermediate water dwellers, adapted to oligotrophic stable nutrient levels. Named " equilibrium " species, these complex morphotypes correspond to the "K-selected" species of biologists (Mac Arthur and Wilson 1967). They dominated the assemblages throughout the *R. cushmani* Zone. During this high diversity period, other less complex planktic foraminifera, characterized by non-keeled trochospiral and biserial morphotypes (*Whiteinella* pro parte, *Hedbergella*, *Heterohelix*, *Guembelitria*) developed in surface and intermediate waters. Although they never dominated the assemblage at this time, their capacity for adaptation remained high.

The turnover starts at the studied sections with the onset of paleoenvironmental perturbations, which led to the demise of complex morphotype species and furthered the proliferation of primitive morphotypes (Caron and Homewood 1982). These correspond to the "*r* selected" species of biologists. They were unaffected because of their extreme tolerance to fluctuations of nutrient levels, salinity and temperature in surface waters. This association of opportunists is characterized by high abundance of specimens and low species-diversity.

The turnover ends with the reappearance of complex keeled morphotypes (K-selected), including *H. helvetica*. The high species-diversity points to the recovery of a stable oligotrophic environment throughout the oceans. According to our correlation we suggest that the end of the turnover was diachronous. We interpret this to reflect the pattern of circulation of oceanic water masses, which depended on the paleogeographic situation of each site.

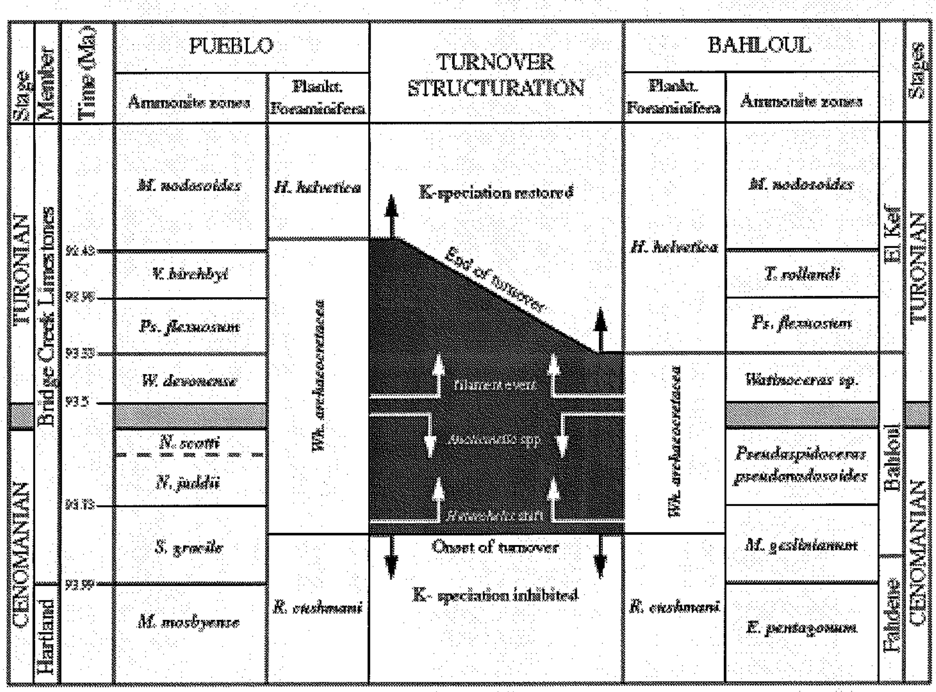

Figure (Caron, Dall'Agnolo et al., Geobios 2005, in press).

Planktic foraminiferal turnover during the Cenomanian/Turonian boundary interval at Pueblo and wadi Bahloul: structure and diachroneity of this turnover relative to chronostratigraphy and ammonite zonation.
Hatched lines mark the precision interval; *dark gray shadow* marks the length of dominance time of *r*-speciation that corresponds to the *Whiteinella archaeocretacea* Zone in both areas.

Breakup of the Northern Tunisian platform during Aptian to Cenomanian times : tilted blocks in Jbel Hameima (El Kef region) and Jbel Hamra (Kasserine region).

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The widespread lower Aptian platform carbonates in Northern Tunisia (Serdj dolomites), are cut by small-scale normal faults observed in two sites : the Jbel Hameima (SW from El Kef), and the Jbel El Hamra located 50 km further south. In both places faulting occurred in the same time interval (Late Aptian-Early Albian times) and the orientation of faults and sense of tilt are the same, thus these extensional features must be representative from the regional paleostress setting in Early Cretaceous times.

- Jbel Hameima : three kilometric-wide, NW-SE oriented tilted blocks were created during Late Aptian times, after the deposition of the early-Late Aptian Serdj dolomitic fm. The resulting relief suffered continental erosion, dissolution and karstification before beeing onlapped by Upper Aptian to Albian transgressive sediments. The pluri-decametric fault scarps show erosional morphologies due to continental exposure and their dip is significantly lower than the dip of normal faults. The slopes are drapped by mineral precipitates which were mined in several sites of the Jbel Hameima, close to the Aptian normal faults. The mineralization occurred after continental erosion since it postdates the development of speleothems in some fissures, but normal faulting was still active (or re-activated) at that time. The mineral crust is covered by Upper Aptian hemipelagic marls with Orbitolinidae.
- Jbel El Hamra : a dense pattern of small-scale, NNW-SSE oriented normal faults is found in the southern and western parts of the jbel. Sequence stratigraphic and biostratigraphic analysis demonstrate that the breakup of the Serdj formation and the final sealing of the blocks occurred in early-Late Aptian and Late Albian times, respectively. A condensed sequence with Early Albian fauna is found in one of the half-grabens, which are tilted towards the NE. This fault pattern is cut by larger-scale, E-W to NW-SE normal faults associated with southward or SW-ward tilting. Aerial and satellite images show that these more recent faults were active during Late Albian to Cenomanian times, and are finally sealed by a major erosional angular unconformity below the Turonian Bireno fm. These latter faults are possibly linked with halokinetic activity.

The onset of NE-SW extension during early-Late Aptian times, as documented by our observations, is consistent with regional synthesis, which point to an important Aptian tectonic shift (Barrier et al., 1993 ; Bouaziz et al., 2002 ; Patriat et al., 2003 ; Soyer & Tricart, 1997). From geodynamic point of view, as discussed by Barrier et al. (1993), the development of NE-SW extension since early-Late Aptian times in Tunisia can be related either to the Eastern Mediterranean rifting, or to the kinematic reorganization following the connection of the Southern and Central Atlantic oceans which occurred at that time (Guiraud & Maurin, 1991).

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Record of Aptian-Albian relative sea-level changes in microcave infillings. The example of Jebel El Hamra, Tunisia

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The paleogeographical framework of Cretaceous in Tunisia is characterized by a continental domain in the South (the Sahara platform domain) and an open marine domain in North (the "Tunisian trench" to the North West and "The North Pelagic Sea" to the North east. The transition is done by an intervening carbonate platform in the centre (the "platform of the pelagic sea"). (J.Marie et al., 1980; M'Rabet, 1981).

The section of the Aptian/Albian of Jabal el Hamra is a part of this zone of transition from platform to basin and offers the possibility to follow the evolution from the North to the South.

In the section of Aptian/Albian of El Hamra, the Aptian is represented by a platform that belongs to "the Large and resistant area" corresponding to the "High ground of central Tunisia" (J.Marie et al., 1980).

The uppermost surface of the Aptian platform in El Hamra is characterized by a major unconformity associated with important diagenetic anomalies and dolomitization.

During Upper Aptian (Echihaoui, 2004), the platform is exposed to meteoric conditions (erosion, alteration) that resulted in significant karstification and dolomitization. The stratigraphic hiatus is important; the carbonate beds of the platform (Upper Aptian) are relayed by marls and shales of Fahdène formation (Upper Albian).

However, the karstic fillings contain reworked pebbles of Late Aptian to Middle Albian and hemi-grabbens contain locally preserved deposits of Middle Aptian to Middle Albian.

The first unconformity in the the top of the platform is the D4 represented here by an important fractures and karsts with various fillings. The reworks in the calcareous beds that surmount the D4 show pebbles of micritic mud with pelagic foraminifera (*Favusella*) resulted in open marine deposit that have relayed the conglomerates in the top of D4 surface, reworking of orbitolina are also found (*Mesorbitolina parva*) this indicate that the age of the sequence is Late Aptian and corresponding to the first maximum flooding surface.

These reworking beds are ended by a new surface of karstification.

The latter is relayed by open marine marls with Ammonites *D. mammillatum* indicate the Lower Albian and equivalent to those of the first sequence of Hameima (Jaillard et *al.*, this volume) and ending by another surface of karstification.

This sequence is relayed by transgressive calcareous marls which contain in the base Ammonites (*Lyelliceras pseudolyelli*) indicating the latest Early Albian. The marls continue with a covered level probably corresponding to Middle Albian. This sequence is ended by calcareous beds rich in crinoids, ammonites and phosphate and representing the sequence boundary of this sequence.

The Aptian/Albian section of El Hamra records three maximum flooding events corresponding to three sequences with the followed ages:
1-First sequence in Early Albian.
2-Second sequence in latest Early Albian
3-Third sequence in early Late Albian.

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Hétérogénéité séquentielle à l'échelle globale à la limite Cénomanien-Turonien

Outphased sea-level changes in world basins by the Cenomanian-Turonian boundary

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The Cenomanian-Turonian boundary anoxic event (OAE2) is associated with both a 13C positive excursion and a crisis in planktic foraminiferids. The anoxic event is widely thought to have taken place during a major global transgression. We show this is not true. The idea of a global transgression coincidental with the C/T boundary is often based on the interpretation of fine-grained basinal deposits hosting the boundary black shale, but not always on data able to clearly depict relative sea-level changes, like the displacement of facies belts with changes in base level in coastal deposits. After a study of a number of basin margins we evidence instead outphasings of relative sea-level changes close to the C/T boundary. The consequence is that the event has to be associated with a global and short-lived tectonic pulse rather than with a global transgression.

As a whole, in many sedimentary basins, most of the late Cenomanian is represented by a single major progradational phase after a strong transgression which operated by the beginning of the substage. The same is true for the early to middle Turonian intervall. What occurs in between, that is, by the C/T boundary, is more complicated.

In the French subalpine basin (SE France), two platform-to-basin transects have been made, in order to obtain reliable sea level curves from the displacement of facies belts over the whole late Cenomanian – early Turonian intervall. On the western margin, a strong forced regression is observed by the C/T boundary, with a small « lowstand » turbidite system interfinguered in the black shale intervall, while the shoreline shifted basinward over more than 80 km. Contrarily, no clear relative sea-level changes are recorded on the southern margin (Castellane area, where is the type section of the Thomel black shale). Further to the south, on the northern border of the south Provence saddle, Gindre (2003) has also evidenced a drop in relative sea-level by the C/T boundary but milder than on the western margin of the subalpine basin. So, at the scale of a single basin, a strong heterogeneity in terms of sea level changes is found, which is explained by a short-lived tectonic pulse.

In the North-American Western Interior, which is a foreland basin where most of shoreline shifts can be explained by changes in the stress field, one of the strongest transgression is observed (base of the Bridge Creek limestones) from the uppermost Cenomanian to the lowermost Turonian.

In western Morocco (Atlantic margin), the 13C excursion covers a T/R depositional sequence between two emersion surfaces, in oyster-bearing, shallow-water limestones and marls. The major transgression clearly post-date the 13C excursion and is early Turonian in age. It is represented by laminated, organic-rich chalks or marly chalks. There, the « black shales » are clearly transgressive but not of same age than in SE France where they were deposited a bit earlier, mainly during the 13C excursion.

In the north Saharan basin (Tademait and Tinrhert areas), the marine flooding began by the beginning of the late Cenomanian which is represented by open-marine, shallow-water bioclastic chalks resting on lower Cenomanian evaporite facies. The flooding then continued without any intervening drop in relative sea-level well into the lower Turonian. The C/T boundary so lies within ammonite-bearing, fine-grained chalks representing a sea-level highstand.

On the Levant platform, the C/T boundary lies within fine-grained, finely-bedded limestones between the upper Cenomanian and the lower to middle Turonian major carbonate platform prograding sequences, that is within a sea-level highstand as in the north Sahara basin.

The heterogeneity we found within the short C/T boundary intervall could be also true for the whole Cenomanian below, judging from our data and those from the litterature. On the contrary the lower to middle Turonian seems to be more sequentially homogenous at the global scale.

So, we think there are no clear evidence of synchronous relative sea-level changes in the Cenomanian and especially at the C/T boundary. We explain this by a global tectonic control rather than a eustatic control on depositional sequences, with a peak heterogeneity by the C/T boundary. The lower to middle Turonian would correspond to something like a relaxation phase with more sequential homogeneity.

Argon geochronology for Geological Time Scale calibration : uses and abuses

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Numerical dating of rocks uses the radioactive decay of natural unstable isotopes of the Earth crust. Due to its wide range of application, the K-Ar method is usually favored to constrain the "absolute time" in the geological successions. Two techniques are in use, K/Ar and $^{40}Ar/^{39}Ar$.

The main interest of the K/Ar technique is its suitability for both low temperature minerals (glauconite, illite) and high temperature minerals (micas, K-feldspars). The disadvantages are the relatively large amount of material needed (100 mg minimum) and the age uncertainty limited by the K determination (about 1 %).

The $^{40}Ar/^{39}Ar$ technique is now preferred, mainly because it requires a very low amount of material, the step heating approach allows to check that the system remained undisturbed, and, it yields very low apparent analytical uncertainties (sometimes less than 0.1% for K-rich minerals). However, the uncertainty on the absolute age used for geological time scale calibration must include the age uncertainty of the flux monitor (standard), which is not known to better than 1-2%. Moreover, the age of the standards have been re-calibrated recently, and, again, will probably be subjected to revision in the future.

The recent Lower Cretaceous geological time scale (LCTS) proposed by Gradstein et al. (2004) is calibrated mostly with $^{40}Ar/^{39}Ar$ data and rare U/Pb ages, coupled, in some cases, with orbital tuning (evaluation of relative duration). However, most $^{40}Ar/^{39}Ar$ stage ages should be regarded with caution, because:

(1) their stratigraphical attribution is often indirect, or not very precise (ammonite zone), or assumed by endemic ammonites (e.g. Western Interior),

(2) of the poor quality of the analyzed, often weathered, material (micas, basaltic whole rock), from Pacific seamount basalts or bentonites, for instance, associated with underestimated uncertainties,

(3) many were obtained from poorly suitable material such as plagioclase (low K, high Ca) or whole rock, the latter being often used for the Pacific guyots dating.

Such appraisal led us to propose an alternative calibration of the LCTS constrained by direct K-Ar absolute dating of each stage and orbital tuning.

Ten glauconitic horizons sampled in the Vocontian basin (SE, France) from the base of the Lower Hauterivian to Upper Albian, yielded K-Ar ages from 123.3 ± 1.7 Ma to 96.9 ± 1.4 Ma, respectively. The relative duration of each stage has been derived by the cyclostratigraphy previously obtained in the Vocontian and Umbria-Marche basins. Using the GL-O standard from the Albian-Cenomanian boundary at 95.3 Ma as the anchor point, a cyclostratigraphic age for each stage boundaries has been extrapolated and thus compared with the K-Ar ages. This shows a very well-defined linear correlation which demonstrates the robustness of the proposed Lower Cretaceous Time Scale. It also shows that glauconite minerals are powerful radiochronometers, when precisely stratigraphically defined and carefully selected.

THE APTIAN-TURONIAN RECORD IN THE HELVETIC ALPS: THE FILTERED IMPRINT OF GLOBAL EVENTS ON THE NORTHERN TETHYAN SHELF MARGIN

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During the Aptian-Turonian time interval, the Helvetic realm along the northern Tethyan margin experienced a phase of profound reorganisation, which is expressed in the final drowning of a shallow-water carbonate platform, a subsequent phase of sediment starvation and formation of glauconite and phosphate-rich deposits, and the final take-over of a pelagic regime of carbonate deposition.

During the early Aptian, the evolution of the northern Tethyan carbonate platform is marked by an important progradational phase in a predominantly photozoan mode of carbonate production. The thus deposited beds were subsequently subjected to a phase of erosion and local phosphogenesis, which led to an incipient drowning of the platform. This phase is situated somewhere near the boundary of the *weissi* and *deshayesi* zones and pre-dates as such the oceanic anoxic event OAE 1a. Subsequently, carbonate production took up again in a heterozoan productional mode and a shallowing-upward sequence is deposited, but only sporadically preserved. Within this sequence, a phase of phosphogenesis occurred, which is dated by the presence of *Deshayesites* and by means of □^{13}C chemostratigraphy, and is interpreted to represent an equivalent of OAE 1a. Consequently, an important drowning episode occurred, which is expressed by erosion, phosphogenesis, and condensation and lasted from the *furcata* to the *melchioris* and *nolani* zones (late early to middle late Aptian). It is not clear if this phase can be correlated to an OAE. A final, strongly progradational phase of shallow-water carbonate production in a heterozoan mode occurred during the *nolani* zone. This phase was followed by a terminal platform drowning phase – expressed by erosion, phosphogenesis, and condensation, which lasted from the *jacobi* to the *tardefurcata* zone (limit Aptian-Albian) and correlates to OAE 1b p.p.

During the Albian, several phases of condensation and phosphogenesis occurred, which lasted from the *tardefurcata* to the *mammilatum* zone, the *inflatum* zone and the *dispar* to the *rotomagense* zones. These phases appear to correlate to OAE 1b p.p., OAE 1c and OAE 1d. In distal areas, one single phase of condensation and phosphogenesis is observed, which lasted throughout the Albian.

Pelagic carbonate sediments started to be deposited in the latest Albian in distal areas; their deposition moved on towards more proximal areas during the early Cenomanian and somewhere near the middle Cenomanian, the entire helvetic platform was covered by pelagic carbonates, except for the area of the former carbonate platform margin, where condensation and erosion continued well into the Turonian.

The latest Cenomanian pelagic carbonates of the Helvetic shelf lack any expression of OAE2, which is rather enigmatic. Mid-Turonian pelagic carbonates are characterized by the widespread occurrence of red beds. The Turonian is also a period where a phase of widespread erosion and resedimentation processes started in the distal part of the shelf. This phase continued intermittently during the remainder of the Cretaceous.

Whereas during the Aptian and Albian – during the demise of the shallow-water carbonate platform and consequent phases of condensation and phosphogenesis, the northern Tethyan margin appears to have been marked by global anoxic events, this seems less the case for the Cenomanian-Turonian phase of pelagic deposition, where some sort of enigmatic filter prevents OEA 2 to be expressed in the helvetic sedimentary record.

Correlation of organic-rich deposits, sea level changes, platform drowning and fault activity in the Organyà rift basin (southern Pyrenees, Spain)

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The way that rift dynamics promote the cyclic accumulation of organic carbon in sediments at million year time-scales has been examined in the Organyà basin, one of the grabens that extend the Bay of Biscay rift into the Iberian plate (Fig. 1). Organic-rich deposits are common in the centre of the Organyà basin throughout the late Barremian, Aptian and early Albian, coeval with the rift maximal.

Late Barremian sediments consist of dark lime-mudstones and wackestones deposited in a shallow lagoon, representing restricted conditions. Similar facies have been described elsewhere in the Pyrenees, and possibly result from bad connections of the rift system with the Atlantic and Thetys oceans. The absence of terrigenous suggests a very low relief of the rift shoulders.

The aptian transgression, shown in the Haq *et al.* (1988) eustatic curve, is overprinted in the Organyà basin by a rapid sea level rise produced by fault-driven subsidence (Fig. 2). Deepening was achieved in the basin centre by outpacing the average sedimentation rate of 0.33 mm/yr. Since the transgression was accompanied by the input of important amounts of terrigenous clay bearing organic matter, primary production is thought to rise from the Aptian onwards, satisfying one of the conditions for the formation of organic-rich deposits. Other general conditions are a low energy depositional environment, the degree of dilution in mineral matter and the development of anoxicity (Killops & Killops, 2005).

Organic-rich deposits. The first deposits (#1 and 2) consist of black, laminated lime-mudstones, formed by pelagical carbonate fall-out at the beginning of the aptian transgression (Bernaus 2000). They have been tentatively correlated with the Selli OAE1a by the same author. Carbonate deposition halted at the top of deposit #2, though reefal banks continued to develop in the basin margin (Fig. 1).

The next six organic-rich deposits consist of dark-coloured marls with thin turbidite beds reworked from the slope and the top of the carbonate banks. Viewed in cross-section, the majority correlate with drowning surfaces, erosional surfaces and omission surfaces, produced by the syn-extensional rotation of carbonate banks on fault blocks (García-Senz, 2002). Dark-coloured marl deposits #1, 2 and 8 were laid down in a rapid deepening sea, which attained sufficient depth to maintain the stratification of the water column and the anoxicity for long periods (Fig. 2). On the contrary, deposits #4, 5, 6 and 7 formed during short episodes of rapid sea-level rise, in a progressively shallow sea. Facies cyclicity between levels #5 and 7 include well oxygenated grainstones, orbitolina marls and dark-coloured marls with tempestites.

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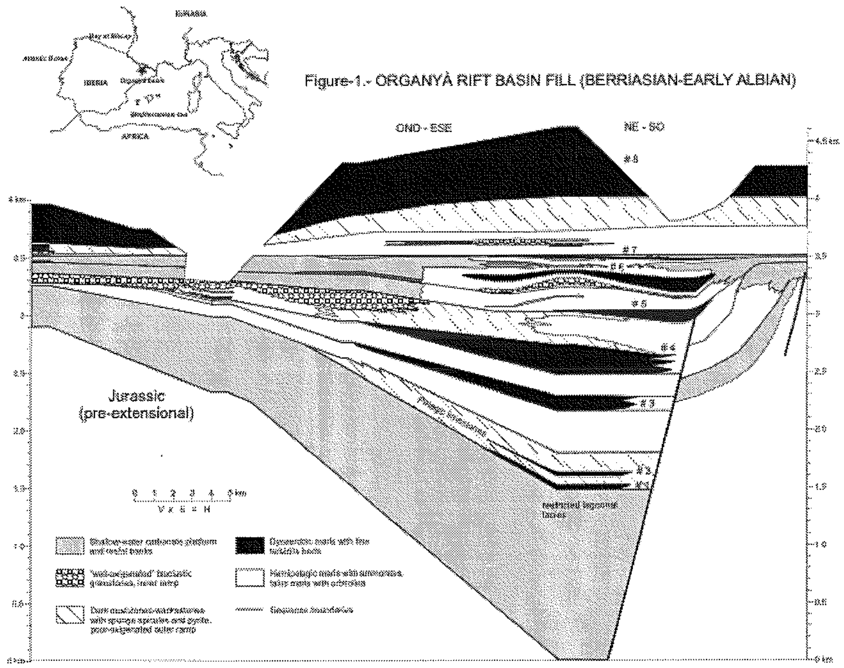

Figure 1.- Stratigraphic cross-section of the Organyà rift basin, showing the main facies and the dysaerobic intervals.

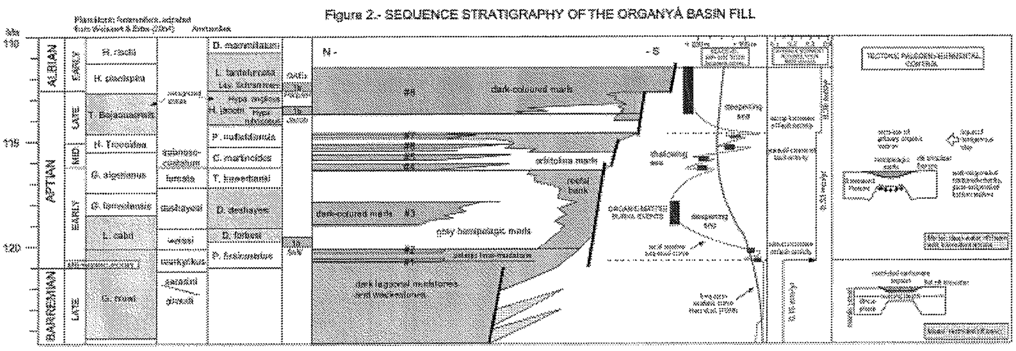

Figure 2.- Sequence stratigraphy of the Organyà basin fill. Dysaerobic intervals are correlated with the eustatic and local sea level curves, the average sediment accumulation, and rift tectonics.

Development, emersion phases, and drowning of the Albian-Turonian Natih carbonate platform, Oman

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The Albian-Turonian Natih Formation is the youngest carbonate system to have developed on the eastern Arabian Plate during the reasonably quiescent time following the phase of rifting from the Indian Plate in the Jurassic, and that lasted up to the late Cretaceous obduction of the Semail ophiolite.

The Natih developed as an extremely broad, fairly shallow platform over what is now central to northern Oman, with time equivalent deposits to the northwest within the Mauddud, Shilaif and Mishrif Formation, and a high energy platform to slope transition to the north, slightly beyong at the position of the present day northeast coastline of Oman.

The Natih has been shown to comprise three main stratigraphic sequences and is built up within those, by numerous higher frequency cycles. The greater magnitude of relative sea level change that caused the first and third cycles, compared to the rather moderate production of carbonate, led to the creation of intra-platform basins some 50 to 80m deep. Conditions during the development of these basins allowed preservation of kerogen rich chalks, whereas decreasing accommodation then resulted in progradation of higher energy rudist dominated shoals, progressively filling in the basin morphology.

The three stratigraphic sequences are fairly isopachous, and the resulting carbonate packages are separated by extensive if not very thick clays, derived from the Arabian massif to the south and west, or from decalcification of previous deposits, and laid down during the sea level lowstands to early transgressive stages. Carbonate facies distributions and heterogeneity, established from outcrop and core, are both shown to be different during the transgressive and regressive phases of each sequence. The depositional profiles, deduced from outcrop studies and confirmed from seismic, show a concomitant change from lower angle ramps during transgression, to higher angle clinoforms with a platform-slope break during regression. Models of the detailed stratigraphy of each sequence, taking into account the geometrical constraints established from seismic, provide a very different picture to those most commonly established from correlation of regionally spaced sections, whether from outcrops or from well data. Correlations between sections or wells must take into account established geometrical constraints.

The end of each of the three cycles was defined by sea level falling below the platform top. During these times of emersion, minor to minimal karstification occurred, but surface water flow was sufficient to incise bedrock and to sculpt channel systems. These incisions have been observed and closely studied both on outcrop and on seismic. Seismic forward modelling of channel features, based on outcrop observations, has allowed improving the interpretation of such features from 2D and 3D seismic. The incisions indicate a sea level drop of at least 20m below the platform margin at the end of the first sequence (Natih e), providing some calibration for eustatic variations at this time. Flooding of the eroded platform tops during subsequent transgression led to aggradation of tidal channels and mudflats before the re-establishment of the broad shallow-marine platform.

The third sequence, after increasing accommodation and again limited carbonate production gave rise to an intrashelf basin with kerogen rich chalks (Natih b facies), shows evidence of structural activity having forced the regression of platform margins out over the intrashelf basin. Incision at the top of the Natih then sculpted channels ("canyons") up to 150m deep in some locations, another indication of the structural uplift that terminated the Natih platform development. Deep water shales overlie the Natih, evidence of the drowning of the carbonate platform after emersion and incision, and in the Oman Mountains these contain debris flows and olistoliths derived from the Hawasina thrust units. The third Natih sequence is thus terminated by a tectonically enhanced boundary, and the whole third sequence may have been somewhat governed by the overprint of tectonics on a eustatic signal.

Natih carbonate platform development and demise took place under strong eustatic and growing structural constraints. Carbonate platform development of the Natih is thus shown to be controlled predominantly by eustatic cycles, with a growing role of tectonics that dominated at the end, and by an oceanographic and atmospheric "mood" that was such, in this area, to temper carbonate production sufficiently to allow the development of intrashelf basins.

The same "mood" presumably favoured the development of rudists on the platform, and governed the preservation of source rocks within the intrashelf basins. This resulted at least twice in complete petroleum systems comprising source rocks, reservoir rocks and seals.

Hydromagnetic Alfven waves induced in the earth's core by variations of magnetospheric currents over the solar cycle

Dominique Jault

We show that the main magnetic field at the CMB is strong enough that the magnetospheric electrical currents that vary over the solar cycle produce magnetic fields that penetrate deeper than the electromagnetic current skin on the core surface and excite hydromagnetic Alfven waves within the core. These waves consist of geostrophic motions (oscillations of cylindrical annuli about the rotation axis). They yield variations of the internal magnetic field over the solar cycle that must not be mistaken for fields induced in the solid mantle. In addition, these variations of core origin do not share the symmetries of the external source because the geometry of the main field at the CMB is complex.

This can explain some old results by Harwood and Malin (1977). They found evidence, in their study of the variation of the geomagnetic field associated with the sunspot cycle, of variations that are symmetrical neither about the geographical axis nor about the dipole axis but that have a timescale comparable with the solar cycle.

Finally, we investigate whether modulation of magnetospheric currents over the 22 years of the solar cycle may excite also hydromagnetic waves within the core. We discuss whether the intensification of the amplitude of these waves upon their arrival at the cylindrical surface tangent to the solid inner core and/or near the equator may explain very rapid features of the magnetic secular variation, such as geomagnetic jerks.

LES EFFETS THERMIQUES DES INTRUSIONS MAGMATIQUES SUR LES ASSOCIATIONS DES MINERAUX ARGILEUX DE SUBSURFACE (cas du crétacé de la marge orientale de la Tunisie).

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L'activité volcanique du Crétacé se trouve occasionnellement et localement au cours de l'intervalle Berriasien-Maastrichtien. Les intrusions magmatiques du Crétacé inférieur sont discontinues dans le temps et dans l'espace. La répartition dans l'espace de ces intrusions se trouvent préférentiellement le long des directions E-W et N140 qui sont rangées comme des directions tectoniques majeures. Ces directions structuro-magmatiques ont été activées en failles normales au cours du Crétacé. L'abondance des filons accompagnant l'activité effusive suggère un magmatisme de type fissural. Les laves basaltiques forment l'essentiel de ce volcanisme. L'identification des minéraux argileux se trouvant en contact d'intrusions magmatiques et recoupées par des sondages pétroliers implantés dans le Sahel et la mer pélagienne a été réalisée par la diffraction des RX et par le MEB. La caractérisation minéralogique nous a révélé l'existence de deux associations de minéraux argileux : (1) Dans les sondages pris comme référence et dépourvus d'intrusions magmatiques, nous avons identifié la kaolinite, la smectite, l'illite, les minéraux interstratifiés et une phyllite ayant un feuillet élémentaire compris entre 11 et 13 Å. (2) Dans les sondages comportant des intrusions magmatiques, la composition minéralogique montre la présence de la kaolinite, la smectite, l'illite, les interstratifiés et la chlorite. Certaines entités minérales présentent une bonne cristallinité indiquée par les arrêtes et la forme bien dégagée des cristaux, alors que pour d'autres, situées au contact direct avec l'intrusion volcanique, l'aspect est déchiqueté avec des cristaux mal individualisés. La présence de la chlorite au voisinage des intrusions magmatiques (essentiellement basaltique) est un marqueur d'un gradient de température en relation avec ce volcanisme syn-sédimentaire. Il y a donc un transfert de chaleur des intrusions magmatiques ainsi que les fluides qui leur sont associés vers les roches sédimentaires encaissantes. L'augmentation de la température au voisinage de l'intrusion entraîne la croissance de nouveaux minéraux (chlorite). L'évolution de la nature des minéraux argileux avec la profondeur montre également une augmentation du pourcentage de l'illite et de la chlorite au détriment de la kaolinite, de la smectite et des interstratifiés. Ce phénomène est à relier à la diagenèse d'enfouissement.

Les deux facteurs, gradient géothermiques et l'enfouissement ayant joué simultanément et dont les effets sont signalés par la variation des associations minéralogiques des argiles de subsuraface.

Mots clés : Tunisie orientale, Crétacé, sondage pétrolier, magmatisme, métamorphisme, diagenèse d'enfouissement, minéraux argileux, DRX, MEB.

Linking Tectonics, Climate Change and Biotic Evolution: The Oceanic Anoxic Events of the Mid-Cretaceous (~121-90 Ma)

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Abstract

Mid-Cretaceous (Barremian-Turonian) plankton preserved in deep-sea marl, organic-rich shale, and pelagic carbonate hold an important record of how the marine biosphere responded to short- and long-term changes in the ocean-climate system. Oceanic Anoxic Events (OAEs) were short-lived episodes of organic carbon burial that are distinguished by their widespread distribution as discrete beds of black shale and/or pronounced carbon isotopic excursions. OAE1a in the early Aptian (~120.5 Ma) and OAE2 at the Cenomanian/Turonian boundary (~93.5 Ma) were global in their distribution and associated with heightened marine productivity. OAE1b spans the Aptian/Albian boundary (~113-109 Ma) and represents a protracted interval of dysoxia with multiple discrete black shales across parts of Tethys (including Mexico), while OAE1d developed across eastern and western Tethys and in other locales during the latest Albian (~99.5 Ma).

Mineralized plankton experienced accelerated rates of speciation and extinction at or near the major Cretaceous OAEs, and strontium isotopic evidence suggests a possible link to times of rapid oceanic plateau formation and/or increased rates of ridge crest volcanism. Elevated levels of trace metals in OAE1a and OAE2 strata suggest that marine productivity may have been facilitated by increased availability of dissolved metals, including iron. The association of plankton turnover and carbon isotopic excursions with each of the major OAEs, despite the variable geographic distribution of black shale accumulation, points to widespread changes in the ocean-climate system. Rates of ocean crust production and hydrothermal activity increased in the latest Aptian. This increased tectonic activity likely drove a long-term (Albian-early Turonian) rise in sea level and CO_2-induced global warming. Changes in ocean circulation, water column stratification, and nutrient partitioning lead to a reorganization of plankton community structure and widespread carbonate (chalk) deposition beginning in the Albian and persisting through the Late Cretaceous. These changes may have been facilitated by secular changes in ocean carbonate chemistry due to initiation of heightened hydrothermal activity during the time of OAE1b. We conclude that there were important linkages between submarine volcanism, plankton evolution, and the cycling of carbon through the marine biosphere.

Summary

Turnover (extinction plus speciation) in the planktic foraminifera closely tracks that of the radiolaria, and both groups of heterotrophic protists display the greatest rates of turnover at or near the major OAEs. The autotrophic calcareous nannoplankton were most strongly affected by the early Aptian OAE1a (Selli event) and the Cenomanian/Turonian boundary OAE2 (Bonarelli event). These two events were the most widespread of the OAEs; both were short-lived and associated with increased marine productivity, and both may have been triggered, at least in part, by iron fertilization associated with submarine volcanism. These volcanic events include the eruption of the Ontong Java superplume as a precursor to OAE1a, and combined influences of increased rates of seafloor spreading and/or other submarine volcanism during the time of OAE2. We propose that increased marine productivity during latest Aptian-early Albian OAE1b was also linked to increased ocean crust production and hydrothermal activity as indicated by reduced (less radiogenic) $^{87}Sr/^{86}Sr$ ratios. However, OAE1b encompasses a protracted interval of organic carbon burial in contrast to the black shales of OAE1a and OAE2. A number of different mechanisms created the conditions necessary to accumulate the multiple, but geographically restricted black shale events of OAE1b. However, the large carbon isotopic excursions (up to 2‰) during late Aptian-early Albian time (*Ticinella bejaouaensis-Hedbergella planispira* biozones) indicate that this interval was associated with significant disruptions in the global carbon cycle.

The OAEs were extraordinary events driven by extraordinary forcing factors. Each was associated with pronounced carbon isotopic excursions (1-2‰) and elevated rates of plankton turnover indicating a broad impact on the ocean-climate system, despite the variable geographic distribution of black shale deposition. But how could the ocean be affected on a global scale, and how could elevated marine productivity be sustained for 10^4-10^5 years? We conclude that the mid-Cretaceous OAEs were linked to submarine volcanic activity. We hypothesize that the emplacement of oceanic plateaus and increased ridge crest hydrothermal activity helped to fuel and sustain the elevated levels of marine productivity during the OAEs by way of iron fertilization of the water column. Global

warming associated with increased submarine volcanism also contributed to higher productivity by way of intensified chemical weathering on the land and greater flux of nutrients to the ocean. Perhaps only OAE1a was directly triggered by submarine volcanism, but we suggest that active hydrothermal activity, in particular, indirectly helped to sustain marine productivity on a global scale during the OAEs. Transgression also facilitated the production of marine organic matter and its burial and preservation as condensed intervals of black shale deposition.

Changing nutrient availability and/or upper water column structure were the likely major factors responsible for plankton turnover at or near the OAEs. However, excess CO_2 associated with submarine volcanism may have reduced carbonate availability and seawater pH, thereby contributing to the loss of calcareous plankton during the early Aptian and latest Aptian-early Albian OAEs. For example, the heavily calcified nannofossils (the nannoconids) were seriously affected by the ocean-climate changes associated with OAE1a, and both nannoconids and the largest and most heavily calcified planktic foraminifera were either eradicated or severely depleted at the onset of OAE1b. By contrast, the deepest-dwelling planktic foraminifera, not necessarily the most heavily calcified taxa were eradicated during OAE2 at the Cenomanian/Turonian boundary. This event was likely caused by an expanded oxygen minimum zone associated with elevated productivity, and/or by the decay of the thermocline due an abrupt deep-sea warming event. The turnover event associated with OAE1d in the latest Albian was likewise triggered by a collapse of upper water column stratification due to surface water cooling or an intermediate water warming event.

Increased ocean crust production in the latest Aptian initiated a long-term trend of rising sea level and warming global climate, both of which peaked in the early Turonian (~92-93 Ma). The rising $^{87}Sr/^{86}Sr$ ratios during the Albian record increasing continental weathering rates with rising sea level and global warming, despite the increased submarine tectonic activity that sustained high global sea level through much of the Late Cretaceous. In addition, the deepening gateway between the basins of North and South Atlantic figured prominently in surface and intermediate water ocean circulation by early Albian time, and deep water ventilation by Cenomanian/Turonian boundary time.

OAE1b in the latest Aptian-early Albian was a watershed event in the evolution of planktic foraminifera. This interval also marks the beginning of the end of widespread black shale deposition and the initiation of chalk deposition. According to the hypothesis of Stanley and Hardie (1998), greater rates of hydrothermal activity through the spreading centers altered ocean carbonate chemistry to favor calcite secreting plankton and other organisms. The marked increases in planktic foraminiferal size and degree of calcification during the Albian support this hypothesis. The spread of pelagic carbonate deposition with rising sea level in the Albian also signals a changing planktic trophic regime dictated by increased thermal and fertility gradients.

Our recent work provides evidence that there was a large secular shift in the Mg/Ca of seawater coincident with increased tectonism during Aptian-Albian time based on paired geochemical data (□^{18}O, □^{13}C, Mg/Ca, Li/Ca, Sr/Ca, Mn/Ca) from four deep sea sites (DSDP Sites 392A, 402A, 511 and ODP Site 766A). If Mg/Ca of foraminiferal calcite is interpreted as a paleotemperature proxy, then the decrease in measured Mg/Ca values across the boundary implies substantial cooling of sea surface temperatures. However, □^{18}O paleotemperature estimates based on multi-species planktic foraminifers from the same interval depict warming and increased thermal stratification. After normalizing the Mg/Ca data for both temperature and salinity a negative Mg/Ca shift of ~6 mmol/mol is documented across the boundary, which is thought to be caused by a secular change in seawater Mg/Ca. Following the initial decrease, low Mg/Ca values may have been maintained in the post-Aptian ocean by increasing the area of environments suitable for dolomite production including multiple carbonate platform drowning events, due to transgression and creation of epicontinental seas.

These findings support the significance of the Aptian-Albian boundary as a watershed event in the evolution of the marine carbonate cycle, which may be explicitly linked to tectonic processes, and may have pre-conditioned the oceans for the widespread chalk accumulations of the Late Cretaceous.

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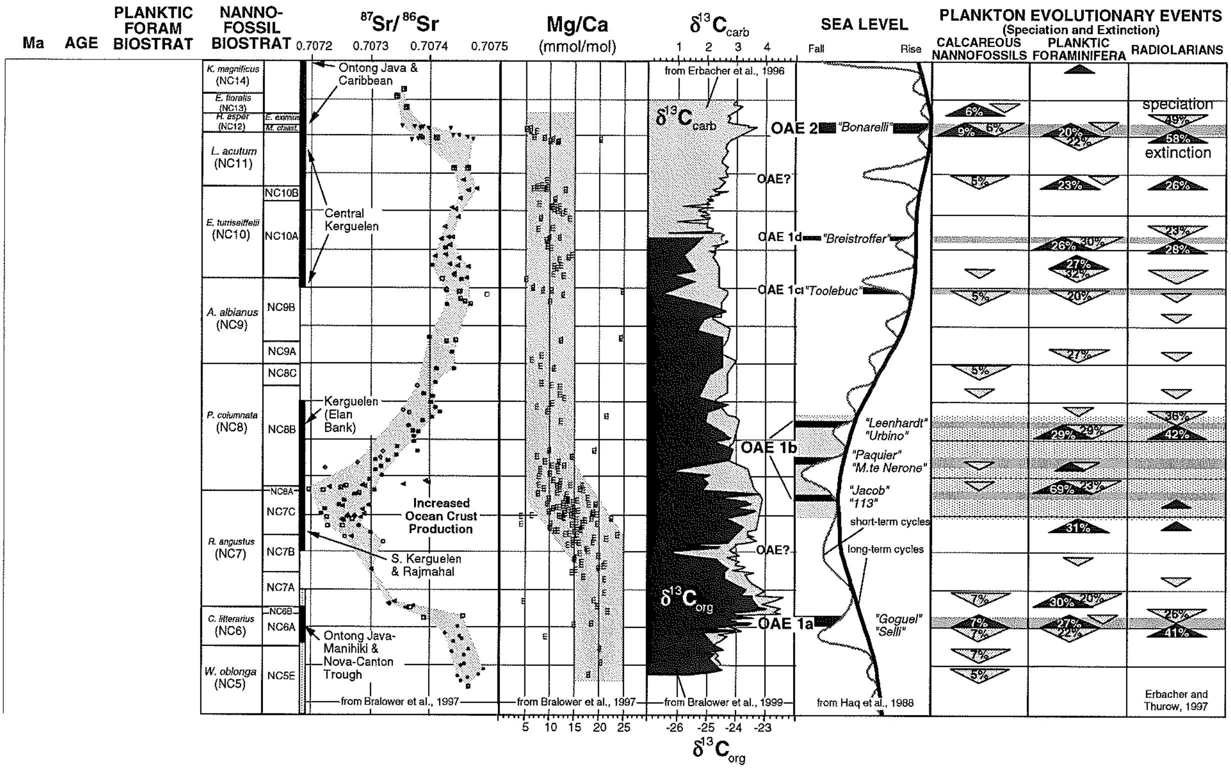

Figure 1. Summary of the major geochemical, tectonic, sea level, and plankton evolutionary events associated with the mid-Cretaceous Oceanic Anoxic Events (modified from Leckie et al., 2002). Note the concentration of evolutionary turnover events (speciation plus extinction) with the OAEs. Also note that OAE1a, 1b, and 2 are temporally associated with increased submarine volcanic activity as indicated by the lower $^{87}Sr/^{86}Sr$ ratios (Bralower et al., 1997), and all three are linked to increased burial of marine organic matter (e.g., Arthur et al., 1987; Erbacher et al., 1996; Larson and Erba, 1999). We hypothesize that submarine volcanism and hydrothermal activity at the spreading centers helped to fuel the elevated levels of marine productivity during the OAEs by way of iron fertilization of the water column. In addition to submarine volcanism, the strontium isotope record is also influenced by continental weathering and runoff (e.g., Jones and Jenkyns, 2001), and the rise in $^{87}Sr/^{86}Sr$ ratios during the Albian may in large measure record increased weathering rates with rising sea level and global warming, despite the increased ocean crust production that sustained high global sea level through much of the Late Cretaceous. We hypothesize that a secular change in Mg/Ca of seawater was triggered by increased submarine hydrothermal activity during latest Aptian time. The post-Aptian ocean favored calcite precipitation as evidenced by the increased size and calcification of planktic foraminifera, the success of rudist bivalves at the expense of scleractinian corals in many places, and by the spread of chalk seas by late Albian time.

Oceanic Anoxic Events and their expression on Carbonate Platforms: the example of the Early Aptian "drowning" of the Urgonian Carbonate Platform

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The Mid-Cretaceous climate change and its sedimentary record have been closely investigated in the past few decades. Based on the information recorded in the pelagic record (e.g. French and Italian sections), the model for the Mid-Cretaceous currently agreed upon suggests extensive oceanic flood basalt volcanism (Ontong-Java and Kerguelen Plateaus) triggering a super-greenhouse effect and thus causing massive and long-lasting paleoceanographic environmental changes including the Oceanic Anoxic Event 1a with black shale deposition in the pelagic realm as well as carbonate platform demise, condensation and authigenesis in the neritic realm.

In the Delphino-Helvetic Realm of the northern Tethyan margin, Early Aptian limestones of the Urgonian Carbonate Platform are overlain by Late Aptian to Early Cenomanian glauconitic and phosphoritic deposits (Formation des Grès Verts Helvétiques a.k.a. Garschella Formation). The essential earliest part of the Mid-Cretaceous sediment record, the documentation of the drowning events, is almost entirely missing though. Only in few, isolated locations in the southern part of the Delphino-Helvetic Realm, this early record has been preserved.

These early relics of Mid-Cretaceous carbonate platform demise are known under the name "upper Orbitolina beds". Outcrop regions comprise the Vercors region of France, Central and Western Switzerland, the Vorarlberg region of western Austria and the Allgäu region in southern Germany. In the most complete sections, the "upper Orbitolina beds" consist of a single, upwards shallowing stratigraphic sequence of heterozoan-dominated sediments, starting with a marly lower part (transgressive systems tract to early highstand systems tract) passing to an upper part with crinoidal-bryozoan, and in some places even oolithic limestones (late highstand systems tract).

The few datable ammonite findings in connection with carbon isotopic correlations to hemipelagic and pelagic key-sections from France (La Bedoule) and Italy (Cismon) suggest a late Early Aptian age of the "upper Orbitolina beds". Notably, we have identified two phosphorite horizons in proximal outcrops of the "upper Orbitolina beds". This is remarkable since 1) phosphorite horizons are often associated with drowning events and 2) these two horizons pre-date the phosphorites of the Formation des Grès Verts Helvétiques (or Garschella-Formation). Whereas the older phosphorite horizon is clearly associated to the initial transgression, the carbon isotopic curve and total phosphorus measurements obtained from more complete outcrops suggest that the younger phosphorite horizon in the calcareous upper part of the succesion may represent the Oceanic Anoxic Event 1a and thus be an equivalent to pelagic black shale horizons like the Goguel respectively Selli Level.

Our reconstruction of newly created accomodation space in the late Early Aptian shows that the "drowning" of the Urgonian Carbonate Platform was perhaps triggered, but shurely not caused by rising sea levels; rather it was the result of environmental stress connected to OAE 1a. Thus, while the direct connection between the pelagic and the neritic sediment record is getting increasingly clear, the concrete processes that led to the Early Aptian platform drowning need to be further investigated. Possible factors involved (and that are to be further investigated) include terrigeneous input in clastics, nutrients, salinity, possible influx of cool boreal waters and the like.

As a part of our ongoing studies we plan to formally define the "upper Orbitolina beds" (in accordance to international regulations) as basal member of the Formation des Grès Verts Helvétiques (respectively the Garschella Formation). This redefinition is based on the affinity of the "upper Orbitolina beds" (especially its phosphoritic horizons) to the overlying mesotrophic to eutrophic sediments rather than to the underlying oligotrophic urgonian limestones.

Biogeochemical Changes During OAE 2: A Multisite Phosphorus Speciation

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Understanding the sources and behaviour of productivity limiting nutrients, such as phosphorus, is critical in our understanding the triggers and development of past climate changes. We present results from a sequential extraction of phosphorus from four sections that differ in their paleoenvironmental situation during oceanic anoxic event 2, (93.5 Ma). The sections are Pueblo (Colorado), Furlo (Italy), Manilva (Spain) and Eastbourne (UK). Mass accumulation rate corrections have been applied in all cases is give P MARs. We also integrate kaolinite and rock-eval data, collected from Pueblo, into our disussion.

We observe a significant peak in all P MARs. The must abundant of these is authigenic in origin. However the first $d^{13}C$ peak is offset from the P MAR peaks by some tens of thousands of years. P MARs tend to rise, initially in step with $d^{13}C$ values but then decrease to pre-excursion values at or just after the first isotope peak. This behaviour is indicative of phosphorus recycling under increasingly anoxic conditions. The regeneration of phosphorus may have sustained productivity beyond that which would have been possible by continental nutrient influx alone. Kaolinite clearly spikes at the base of the isotope excursion in Pueblo, suggesting a brief period of humidity preceded isotope excursion. Rock-eval shows a rapid sea-level transgression at the $d^{13}C$ excursion, which could have reworked the kaolinite and/or remobilised nutrients. The abundance of shallow seas during this period make it possible that one or both of these factors was responsible for supplying the initial nutrient levels to boost productivity. However if productivity was responsible for the characteristic isotope plateaux during OAE 2, then it is unlikely that nutrients alone were directly responsible. The decline in P MAR, as an expression of recycling under anoxia, is an appealing explanation for sustained productivity.

These results give valuable insights into the causal mechanism of OAE 2 and offer new avenues of investigation into the other OAEs that occurred periodically during the mid-late Cretaceous.

Événements tectoniques – sédimentaires aptiens dans le nord du Chili : la fermeture du bassin marin d'Atacama (27°-30° S).

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Mots clés : Tectonique synsédimentaire, Aptien, Nord du Chili, bassin arrière-arc, Relations sédimentation-tectonique-magmatisme.

Aptian sedimentary and tectonic events in Northern Chile: the closure of the marine Atacama Basin (27°-30° S).

***Key words**: Synsedimentary tectonics, Apatian, backarc basin, northern Chile, relations teconics-sedimentation-magmatism.*

***Abstract**: The Atacama sedimentary Basin encompasses calcareous deposits of Valnginian-Aptian age, which are overlain by subaerial volcaniclastic deposits ascribed to the Albian-Turonian. The transition from carbonated to clastic sedimentation is related to important tectonic events, which are well exposed in the Aptian Pabellón Formation.*

From base to top, the Pabellón Fm exibits (1) stratified siliceous limestones, presenting slumps that increase in size upwards (dam to hm), (2) about 50 m of volcanic and volcaniclastic deposits, (3) a short-lived carbonate shelf with heteromorph ammonites, (4) 300 m of massive lavas (ocoïtes), grading laterally to 100 to 150 m of volcanic arenites, with a thin a intercalation of shorface litharenites and with local olistoliths, (5) a prograding, shallow carbonate shelf sequence, interrupted (6) by normal faults limiting grabens and horsts, infilled by volcanic lavas or debris flows, or by a thick olitostrome, including fragments of shallow shelf limetones, and intercalated with ammonite-bearing transgression with Parahoplitinae, and (7) the onset of carse-grained, volcaniclastic fan delta deposits, locally overlain by shallow shelf limestones.

This evolution seems to correlate with the evolution of the neighbouring magmatic arc, which records successively (A) a transpressive deformational event dated at 125 Ma correlated with (1), (B) an extensional phase at 120 Ma, possibly coeval with (3), (C) a new transpressive deformational event at 116 Ma, tentatively correlated with the fan-delta progradation and the definitive intallation of subaerial conditions.

Further studies should verufy such correlatyions, and relate them to magmatic event.

1. Introduction

Le Bassin sédimentaire d'Atacama (27°-29°S) est un des seuls bassins marins d'arrière-arc andin d'âge Crétacé inférieur. Son épaisse série sédimentaire, développée entre le Valanginian et l'Aptian, très bien préservée et richement fossilifère, a enregistré de façon très sensible et continue les événements affectant la marge.

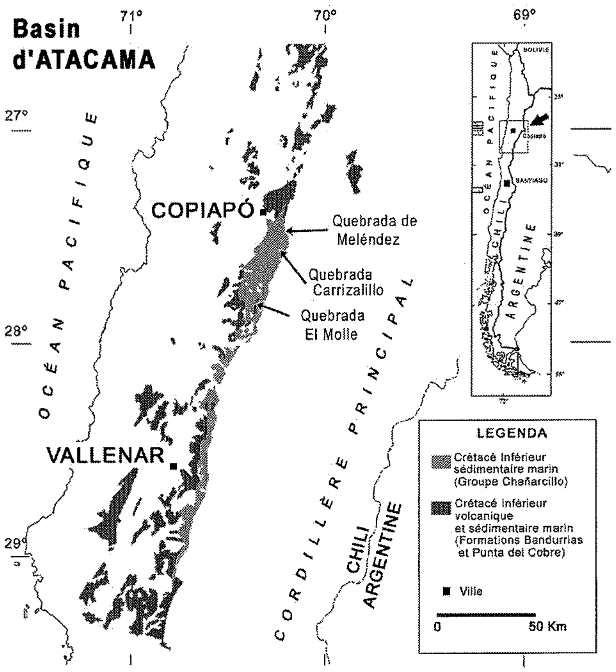

Fig. 1. Les affleurements du Crétacé Inférieur dans le bassin d'Atacama et les localités étudiées.

Les travaux précédents ont divisé la série sédimentaire en quatre formations : Abundancia, Nantoco, Totoralillo et Pabellón, qui composent le Groupe Chañarcillo (Biese, 1942; Biese in Hofftetter et al., 1957; Segerstrom et Ruiz, 1962). La Formation Pabellón montre clairement la succession d'événements survenant pendant l'Aptien, jusqu'à la fermeture et l'émersion du b
assin à l'Aptien sommital (Pérez et al., 1990).

Par ailleurs, l'arc magmatique de même âge a récemment fait l'objet d'études cartographiques, tectoniques et radio-chronologiques détaillées qui ont permis d'établir un calendrier très précis de son évolution tectonique et magmatique (Dallmeyer et al. 1996 ; Scheuber et Gonzalez 1999 ; Arévalo et al. 2003, 2004 ; Arévalo 2005).

Le cadre biostratigraphique que nous utilisons dans ce travail est le résultat préliminaire de nos missions récentes sur le terrain (Fig. 3). Nos observations et le levé de coupes de référence ont porté sur trois localités de la partie nord du basin d'Atacama: Quebrada Meléndez, Quebrada Carrizalillo et Quebrada El Molle (Fig. 1). Le but de cette communication est de présenter les événements tectoniques et volcaniques enregistrés dans la Formation Pabellón et de proposer une corrélation préliminaire avec les événements contemporains affectant l'arc.

2. Stratigraphie de la Formation Pabellon

La Formation Pabellón peut être divisée en sept unités lithologiques majeures, qui sont aisément reconnaissables sur le terrain (Fig. 2).

Nous distinguons une unité basale formée de *cherts* et de calcaires siliceux à grain fin qui passent verticalement à des calcaires de plate-forme. Dans ses deux tiers inférieurs, cette unité a livré des ammonites des zones *Parancyloceras domeykanus* Bayle et Coquand et *Parancyloceras* sp. nov. (Fig. 3).

La sédimentation est ensuite brutalement interrompue par des flux pyroclastiques dont les dépôts ont été identifiés latéralement sur une cinquantaine de kilomètres, avec des épaisseurs observées allant de 30 à 70 m. La reprise de la sédimentation marine est marquée par l'installation d'une nouvelle plateforme, qui enregistre, dans la Quebrada Méléndez, un maximum d'inondation contenant *Ancyloceras* (*Adouliceras*) sp. (Fig. 3).

De nouveaux événements volcaniques sont marqués dans la Quebrada Meléndez par un dépôt épais de 130 m de brèches et grès volcanoclastiques, entre lesquels s'intercalent un niveau de grès de plage au milieu, et des tufs et lapilli dans la partie supérieure de l'unité. Cette unité contient aussi quelques olistolithes isolés. A la Quebrada Carrizalillo, elle est enregistrée sous forme de laves andésitiques d'une épaisseur de l'ordre de 300 m.

La dernière unité de la Formation Pabellón est une plate-forme qui repose sur les dépôts volcaniques qu'elle remanie à la base. Au nord, dans la Quebrada Meléndez, la sédimentation épaisse d'une vingtaine de mètres, montre une transgression avec des facies à *Inoceramus* spp. passant brusquement à un mince niveau de calcaires lacustres. Au sud, dans la Quebrada Carrizalillo, les dépôts équivalents montrent l'installation d'une plate-forme perturbée par des événements tectoniques, définissant des *horsts* et *grabens* et se terminant par l'apparition d'un *fan-delta*. Dans la partie la plus méridionale, à la Quebrada El Molle, cette unité est beaucoup plus épaisse et atteint 350 m d'épaisseur. Elle est caractérisée par la présence d'un olistostrome. Dans cette même localité, deux maxima d'inondation sont marqués par la présence d'ammonites de la sous-famille des Parahoplitinae (*Parahoplites* sp. et *Parahoplites* gr. *nutfieldiensis*), d'âge Aptien supérieur (Fig. 3).

Au dessus, les conglomérats de la Formation Cerrillos reposent en discordance cartographique.

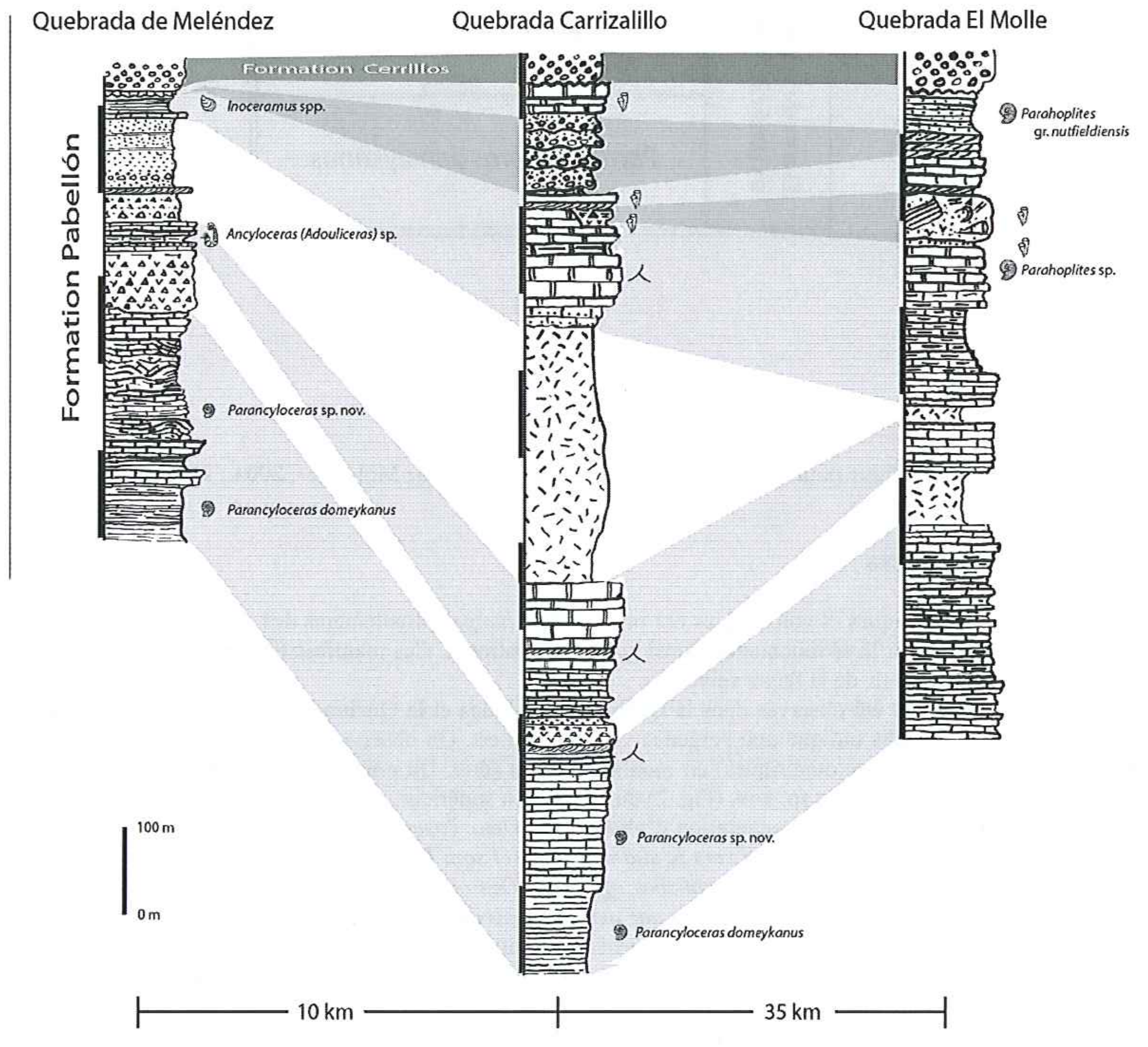

Fig. 2. Schéma stratigraphique des trois localités étudiées.

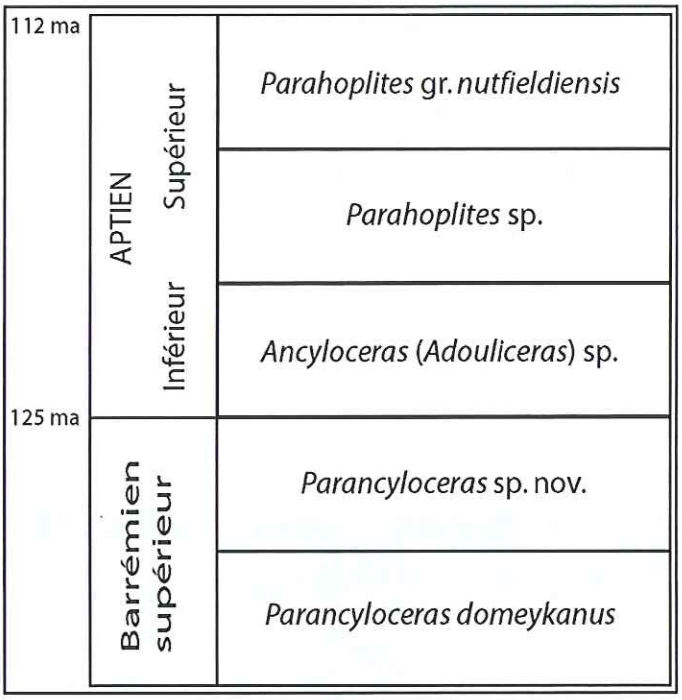

Fig. 3. Cadre biostratigraphique pour l'Aptien du nord du Chili (modifié de Mourgues, 2004 ; âges absolues d'après Gradstein et al. 2004).

3. Signatures tectoniques

Les événements tectoniques et volcaniques ont produit des *slumps*, basculements des plates-formes, olistolithes, *horsts* et *grabens* scellés par la sédimentation, ainsi qu'un olistostrome. Ces manifestations se distribuent, depuis la plus ancienne à la plus récente, de la façon suivante :

Slumps. Les *slumps* ont été observés dans la Quebrada Meléndez et la Quebrada El Molle. Dans cette dernière l'orientation des axes des plis indique une vergence vers le nord-est. On observe une augmentation de la taille des slumps (décamétriques, puis hectométriques) en montant dans la série. Du point de vue biostratigraphique, ceux-ci affectent la zone de *Parancyloceras* sp. nov. (Fig. 2) du Barrémien supérieur.

Basculements de la plateforme et génération d'olistolithes. *Deux basculements ont été observés à Quebrada El Molle, le premier vers l'ouest et le second vers le sud-est. Ceux-ci sont facilement mesurables sur le terrain par de notables changements de pendage entre les couches affectées. Des olistolithes de dimensions hectométriques sont associés à chaque basculement. Ils sont constitués par des calcaires de plate-forme.*

Horst – Grabens et Olistostrome. Les *horsts* et *grabens* se situent près du sommet de la série dans la Quebrada Carrizalillo. Sur la rive gauche de cette vallée affleurent des failles normales scellées par la sédimentation. Celles-ci mettent en contact des calcaires massifs à rudistes, formant les *horsts*, avec des brèches volcaniques et des laves, remplissant les *grabens*. L'orientation des plans de faille donne une direction nord-ouest pour l'ensemble de *horsts* et *grabens*, et une direction d'extension nord-est/sud-ouest. Les failles montrent un déplacement vertical d'une dizaine de mètres. Les grabens atteignent une cinquantaine de mètres de largeur. L'olistostrome est particulièrement bien exposé à la Quebrada El Molle. Il est épais d'une quarantaine de mètres et est formé d'un ensemble volcanoclastique, surmonté d'une brèche calcaire à blocs polygéniques.

Fan-delta. Postérieurement à la structuration en *horsts* et *grabens*, un *fan-delta* à matériel exclusivement volcanoclastique s'est mis en place à la Quebrada Carrizalillo, témoignant de la création soudaine d'un relief. Il est épais d'une cinquantaine de mètres. Au sud, dans la Quebrada El Molle, il se présente sous la forme de *debris flows* remaniés en sables littoraux grossiers par l'action de la mer.

4. Relations arc – basin d'arriere arc

La corrélation des événements enregistrés dans le basin avec ceux reconnus dans l'arc, nous montre une étroite correspondance.

L'augmentation progressive de l'activité tectonique, soulignée par la taille croissante des *slumps* dans la zone à *Parancyloceras* sp. nov. (Figs. 2 et 3) pourrait correspondre à la phase transpressive enregistrée dans l'arc au moment de la mise en place des complexes plutoniques Retamilla et La Higuera à 125 Ma (Dallmayer et al. 1996 ; Scheuber et Gonzalez 1999 ; Irwin et al. 1988 ; Arévalo et al., 2004).

D'autre part, le maximum d'inondation à *Ancyloceras* (*Adouliceras*) sp. de la série de la Quebrada Meléndez, ainsi que l'installation de la plateforme à la Quebrada Carrizalillo, pourraient être liés à la phase extensive datée à 120 Ma (Arévalo et al., 2004). Les *horsts et grabens* de Quebrada Carrizalillo pourraient aussi être liés aux dernières étapes de cette même phase.

Postérieurement, l'inversion des *horst et grabens* serait responsable de l'érosion d'une partie des brèches volcaniques et laves qui remplissent les *grabens*. Le passage extrêmement rapide entre les facies à *Inoceramus* spp. et les calcaires lacustres de la Quebrada Meléndez, témoigne d'une régression importante. Cette inversion serait aussi responsable de la création de pentes générant l'olistostrome de la Quebrada El Molle. Nous la corrélons avec la phase tranpressive datée à 116 Ma (Arévalo et al., 2004). La mise en place du *fan-delta* serait aussi liée à un autre épisode de cette même phase tranpressive.

5. Remerciements

Nous tenons à remercier l'Institut de Recherches pour le Développement (IRD) et le Service de Géologie et de Mines du Chili (Sernageomin), qui ont mis à notre disposition les moyens de développer notre projet. Les recherches d'un des auteurs (F.A.M.) sont soutenues par la bourse chilienne « Presidente de la República» du Ministère de Planification et de la Coopération du Chili (Mideplan).

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BIOSTRATIGRAPHIC CHARACTERISATION OF IVORIAN LATE ALBIAN SEQUENCES.

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A high resolution biostratigraphy study including micropaleontology (foraminifera and nannofossils analysis) and palynology has been carried out upon the Late Albian interval of petroleum offshore wells, in the Côte d'Ivoire (West Africa) sedimentary basin.
This Late Albian interval yields abundant microfauna mostly composed of planktonic foraminifera. Microflora (spores and pollens) are generally abundant through all the Albian interval, apart from the dinocyst specimens which are very rare to absent, as it is for the benthonic foraminifera.

These Albian sediments are composed of claystone or marls interbedded with more or less loose sands layers and rare limestone stringers deposited in a coastal to external continental shelf environment.

The study of planktonic foraminifera and miospores provided a remarkable succession of bio-events which are characteristic of this Late Albian interval. These biozones were calibrated with the electric and lithologic logs and also with the sequence chronostratigraphic chart of J. HARDENBOL and al., 1998. This allowed us the opportunity to give more precision concerning the ages and paleoenvironments determination, as well as the definition of the Late Albian depositional sequences.

Thus, three (3) depositional sequences of third order were identified : Al 10 (100 ma), Al 9 (100.6 ma) and Al 8 (101.5 ma).

Key-words: Biostratigraphy – High resolution - Foraminifera – Miospores – Late Albian – Depositional sequence - Bio-event - Ivorian basin.

Cadre géodynamique de la sédimentation albo-aptienne dans l'Atlas tunisien

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Nous avons depuis 1987, décrit en Tunisie centrale des phénomènes tectono-sedimentaires en relation avec des mouvements compressifs E-W à WNW-ESE d'age aptien supérieur – albien inférieur.

Dans ce domaine (fig.1), cette tectonique compressive qui s'exprime par des plis synsédimentaires, et des discordances angulaires (fig. 2 et 3), a engendré des structures plicatives moulées sur des accidents anciens N-S (le long de l'Axe Nord-Sud, faille de Sidi Ali Ben Aoun) et N20 (Jebel Mrhila, Jebel Serj, Jebel Hamra). Lors de cette phase, les failles anciennes orientées N120 à N80 (faille de Kasserine, Rohia) parallèles à la direction de la compression, rejouent avec une composante normale. Il en résulte la formation de grabens ou de demi-grabens. Dans les zones d'intersection entre les structures plissées et les fossés d'effondrement se développe une activité diapirque (Hamra, M'rhila).

Dans l'Atlas septentrional de tels phénomènes associés à des mouvement diapiriques ont été matérialisés par le développement de discordances angulaires entre les dépôts de l'Albien supérieur et les structures salifaires (Perthuisot, 1978, 1988 et Chikhaoui, 2002).

Cet enregistrement géotectonique a été ensuite confirmé en sub-surface par les pétroliers, notamment dans le golfe de Hammamet et la région de Mahdia où des paléo–hauts submeridiens d'age aptien supérieur – albien inférieur, ont été décrits.

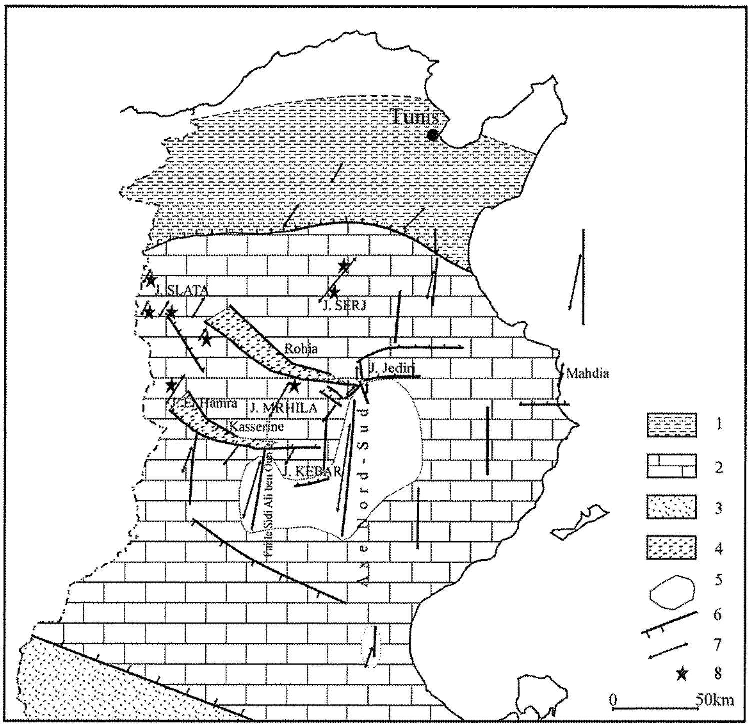

Fig. 1. – Cadre tectonique et paléogéographique de la Tunisie au cours de l'Aptien supérieur-Albien inférieur. 1 : domaine marin profond, 2 : domaine de plate forme, 3 : domaine sub-continental, 4 : zones effondrées, 5 : zones émergées, 6 : Faille, 7 : plis, 8 : récif.

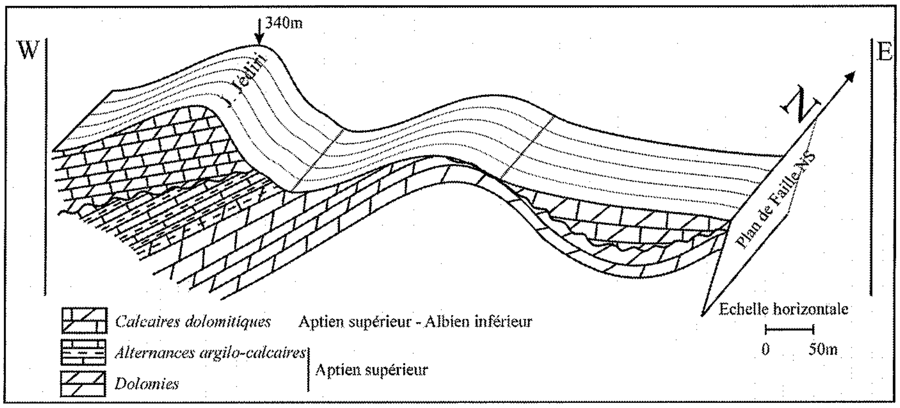

Fig. 2. – Coupe schématique montrant une discordance intra-Aptien supérieur (Jebel Jédiri, Axe Nord-Sud).

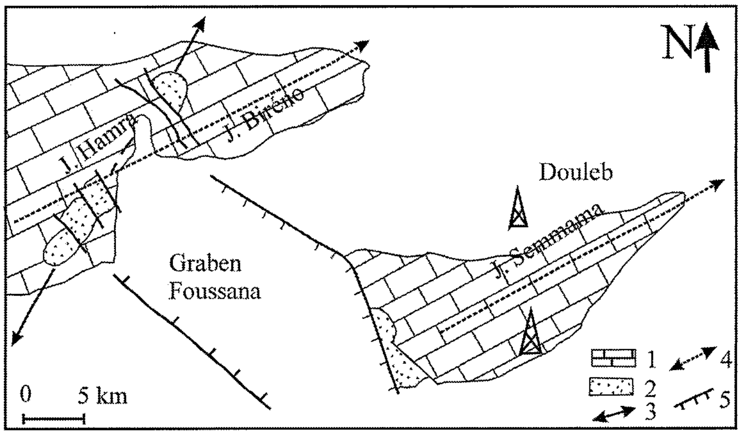

Fig. 3. – Superposition de structures albo-aptiennes (3) et atlasiques (4). 1 : Crétacé supérieur, 2 : Crétacé inférieur, 5 : failles normales.

La multiplication des observations (surface et subsurface) souligne l'importance de ce phénomène à l'échelle régionale. Cependant le cadre tectonique global de cet évènement apto-albien (connu sous le nom de « phase autrichienne ») n'a pas encore été suffisament élucidé.

Nos nouvelles investigations de terrain et de subsubsurface combinées aux données de la cinématique des plaques fournies par les cartes du programme Téthys (1993) et Péri-Téthys (2000), nous incitent à rattacher cette tectonique compressive à un éventuel blocage du déplacement vers l'Est de la marge nord africaine, suite au début de l'ouverture d'une ride en mer de Libye (la Mésogée).

L'expression sédimentaire et stratigraphique associée à cet événement tectonique majeur s'est traduite par d'importantes variations de faciès et d'épaisseur, mais surtout par l'individualisation de hauts fonds à constructions récifales (Jebels Serdj, Hamra et Slata, etc...) et des moles allongés selon une direction NNE-SSW à N-S soumis à l'érosion (Axe nord-Sud, Sidi Ali Ben Oun). Au sein de cette méga-platforme s'individualisent des grabens à sédimentation continue et épaisse (intra shelf basins) tel que celui de Rohia situé au Nord du J. Mrhila.

About the abrupt $\square^{13}C$ variation near the Cenomanian-Turonian boundary: connected to variations of the Earth's magnetic field intensity ?

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Key words: Cenomanian, Turonian, Cretaceous, isotopic variations, $\square^{13}C$, geomagnetic field intensity variations, solar matter ejection, solar particles, nuclear reactions, $\square^{18}O$, boron.

Near the Cenomanian-Turonian transition, a large change in the isotopic ratio $^{13}C/^{12}C$ (i.e. $\square^{13}C$) occurs [1] [2]. This paper wishes to propose a hypothesis about the origin of such an abrupt isotopic variation, based onto a mechanism connected to the variations of the Earth's magnetic field intensity through geological ages.

About a mechanism of variations of the geomagnetic field intensity

The geodynamo model is generally used to describe the origin of the geomagnetic field. The variations and many reversals of the geomagnetic field have been documented from geological records. The reasons for the variations and reversals in the Earth's magnetism are still debated. These variations are believed to be the result of processes operating within the core and/or, to be induced by convective and magnetic interactions at the core-mantle boundary [3] to [8].

In 1987, Laviolette [9] expressed the alternative hypothesis that "... geomagnetic flip could have been initiated as a result of overloading of the Earth's radiation belts with solar cosmic rays. Solar flare particles trapped in the Earth's radiation belts tend to drift equatorially and the ring current so produced generates a magnetic field opposed to that of the Earth. The enhanced solar flare activity (...) could have charged the radiation belt sufficiently to cause a cancellation of the Earth's field, thus initiating a geomagnetic flip.".

What is the evidence to support this mechanism ? Here, as they are rather well documented, I will present evidence from data obtained during recent periods. First, it has been observed that the intensity of the geomagnetic field changed when the ions emitted by the Sun strike the Earth. For instance, in 1859 [10], a magnetic storm occurred at Earth about 17 hours and 40 min after the solar flare begun and the intensity of the geomagnetic field decreased of about -1760 nanoTesla during 1 to 1 ½ hour, corresponding to a decrease of about 5%. The authors [10] reported several other large magnetic storms in the last 150 years with the corresponding measured decrease of the intensity of the geomagnetic field. Laviolette [9] was referring to the end of the Pleistocene corresponding to the end of the last ice age (about 11000 years before present). There is evidence that solar flare activity was very high towards the end of the last ice age. Indeed, Zook et al [11] have studied solar flares tracks left in the glass linings of lunar microcraters on a rock brought back on Earth by an Apollo mission and they came to the conclusion that "... solar flare activity may vary by as much as a factor of 50 on a time scale of 10000 years". In his hypothesis, Laviolette was also referring to a possible effect of solar flare particles onto the Earth's belt. This last effect has been observed directly during a recent large magnetic storm [12]. More generally, the dipole field intensity of the Earth has decreased at the rate of about 5% per century since 1835 [3] while the interplanetary magnetic field has increased by more than two-fold during the last 100 years [13]. In the last decade and during several years, it has been observed that the composition of the energetic particles emitted by the Sun may change greatly from flare to flare. Especially, the enhancement from event to event may vary by a factor of 10 to 10^4 depending on the nature of the isotopes emitted by the Sun [14]. The energy or speed of the particles emitted by the Sun changes from event to event. The nuclear mechanisms induced by these incident particles at Earth are also a function of the nature of the matter ejection event. Here, the expression 'matter ejection event' stands for flares, Coronal Matter Ejection (CME), Solar Energetic Particle (SEP) events either gradual or impulsive, etc.

From these different observations, it may then be extrapolated that a very large quantity of ionised matter emitted by the Sun and striking the Earth over a long and continuous period of time may then led to a decrease of the geomagnetic field, eventually down to its cancellation. The saturation of the geomagnetic field may correspond to a sort of 'geomagnetic disruption' that may induce an erratic motion of the dipole axis during the geomagnetic inversions as it has been documented from some paleomagnetism records [15]. The duration of geomagnetic reversals has been estimated to vary from 1000 to 10000 years depending on site latitude during the Quaternary [16]. This gives an estimate of the length of time during which the Sun can emit a large quantity of matter. The duration of reversals for older geological periods does not seem to be referenced precisely. Even the exact geomagnetic

reformation mechanism with a different polarity by the reduction of the ionic density striking the Earth remains to be described precisely, it may be supposed that this may be linked to the interplanetary magnetic field generated by the Sun. The question of the interactions between solar magnetism and Earth is addressed for instance in [17]. Supposing that very large quantities of ionised matter are ejected more or less continuously by the Sun over a long period of time, the interplanetary magnetic field should be strongly modified and should interfere with the geomagnetic field.
Thus, it seems to me that the different elements presented before are supporting the idea that the variations of the geomagnetic field over time are due to a change of the density of solar particles striking Earth. Forwarding this idea, it should be stressed that the palaeomagnetic records of the Earth's magnetic field may give some insights to the past Sun activity and may help to reshape the model used to describe the Sun in conjunction with present observations. Indeed, it should be pointed out that it has been reported recently that the current Sun model fails to reproduce some present observational aspects [18].

About the abrupt □^{13}C variation near the Cenomanian-Turonian boundary

During the Cenomanian, the average □^{13}C value was about 2-3%. At the end-Cenomanian (about 94 Mys ago), □^{13}C jumped to about 4.5-5 % and then, decreased back to 2-3% at the beginning of the Turonian.
During the decrease or the disappearance of the geomagnetic field, the density of particles striking Earth increases. Shocks between the incident particles and the atmospheric atoms induce the formation of secondary particles such as neutrons, muons, neutrinos, etc [19]. The enhancement of some nuclear reactions between the primary and secondary incident energetic particles, and the atmospheric atoms can induce enrichment in some specific isotopes. For instance, the formation of ^{13}C may occur through the capture of a neutron by ^{12}C. Depending on their energy and on the characteristics of the atmosphere (density, composition, water content, ...), muons and neutrinos may also induce the formation of ^{13}C.
This abrupt □^{13}C variation event lasted about 1 million years. Palaeomagnetic data for the Cenomanian period are scare, it seems that there are some low dipole moment values around that period [20].
Another anterior period can be taken as an example for the link between large isotopic changes and palaeomagnetic variations. Indeed, during the Aptian, there were two periods with an increase of the □^{13}C value to about 4.5-5 %, the first one is dated to about 117-120 Mys and the second one to about 112-114 Mys [2]. Near these dates, it should be noted that paleomagnetism records show some large variations of the Earth's dipole axis [21], this may be interpreted as a period with an unstable very weak geomagnetism field induced by irregular solar activity.
While there was a □^{13}C peak at the end-Cenomanian, there was a □^{18}O decrease at about the same time. Generally, variation of □^{18}O is interpreted as a climatic indicator. High (low) □^{18}O corresponds to cold (warm) climate. If an increase in the solar activity leads to a change in the energetic characteristics of solar particles which may favoured the transmutation of ^{18}O or hindered the formation of ^{18}O (inducing then the decrease of □^{18}O), it should be pointed out that an enhanced solar activity leads also to a warmer climate [17].
Elements such as Sc, Ti, V, Cr, Mn, Co, Ni, Ir, Pt and Au with anomalously high concentration [22] and typical meteoritic ejecta [23] were found near the Cenaomanian-Turonian boundary. These aspects can be related to large solar matter ejection events.

Conclusion

At the end-Cenomanian, the proposed scenario is: 1) Sun activity enhancement inducing an increase of particles striking Earth, 2) this led to the decrease of the geomagnetic field intensity, 3) specific nuclear reactions were favoured leading to isotopic variations, 4) at some point, solar hyperactivity led to the blasting of a huge quantity of matter, the shock wave created by a paroxysmal event should have dragged the materials present in the interplanetary space leading to the metallic enrichment of rocks/sediments and/or to the fall of meteorites, 5) finally, the Sun came back to normal activity, followed by the recovery of the geomagnetic field.
Only one paper [24] reports (three) magnetic inversions at the end of the Cenomanian in the southern Alps within a period of 1.3 Mys. Other systematic geomagnetic measurements are needed so as to give a strong support to the ideas expressed in the present paper.
The enhancement of Sun activity may have also coincided with a change of the atmospheric characteristics. Indeed, a change can have a direct impact onto the type of nuclear reactions induced by the incident particles striking Earth and that occurred in the atmosphere.
Regarding isotopic variations and their possible connections with geomagnetic changes, it should be outlined that boron present into carbonates may be used as a possible sensitive isotopic marker to record any changes in the characteristics of particles emitted by the Sun and/or in the nature of the Earth media in interaction with the incident

particles prior to their capture or transformation. The Earth media correspond mainly to the atmosphere, the upper crust and/or the oceans. The energy of the emitted solar particles is rather high. Reasoning only onto neutrons inducing nuclear reactions, the efficiency of capture by a boron nucleus (^{10}B, ^{11}B) is generally enhanced at low or eventually, at defined intermediate incident energies. Water where carbonates may precipitate, is a very efficient neutron moderator. Boron is naturally present in ocean salts. As the neutron capture cross section between ^{10}B and ^{11}B is very different, any changes in the energetic characteristics of incident particles may lead to a change in □^{11}B or □^{10}B. Spallation mechanisms due to the shock between high energetic solar rays and the atmospheric atoms may induce the formation of boron and beryllium. The isotope ^{10}Be has a half period of 1.6 millions years and transmutes into ^{10}B. Considering spallation, this mechanism may lead to boron enrichment into specific geological formations such as lacustrine carbonates (or ice for recent periods). Solar wind contains also some boron, which may fall directly on Earth [19].

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Mid-Late Cretaceous volcanism, metamorphism and the regional thermal event affecting the Northeastern Iberian basins (Spain).

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The study area includes three main geological units of the NE Iberian Peninsula: the Basque-Cantabrian Chain, the Pyrenean Mountains and the Iberian Chain (Fig. 1). All of them developed by inversion of Mesozoic rifts during the Late Cretaceous-Paleogene. Four Mesozoic evolutionary stages followed by two Tertiary events can be distinguished: 1) late Permian to Hettangian rifting cycle 1; 2) Sinemurian to early Oxfordian post-rift stage 1; 3) latest Oxfordian to middle Albian rifting cycle 2, with development of the Maestrat basin, Cameros basin and the other Iberian basins (Fig. 1); 4) late Albian to Maastrichtian post-rift stage 2; 5) late Cretaceous (Pyrenees) or late Eocene to middle Miocene Basin inversion, and 6) late Oligocene to middle Miocene rifting of the Valencia Trough (Salas *et al.*, 2001).

During the Mid and Late Cretaceous the study area underwent some contemporaneous phenomena such as: alkali basaltic volcanism, metamorphism, thermal heating associated with high thermal gradients, and Hg-Sb bearing deposits.

The volcanic system occurs as a WNW–ESE belt of alkali basaltic character (Fig. 1) along the northern Iberia offshore, the Basque-Cantabrian Range and the Pyrenees. It displays strong lateral variations in thickness and facies and is complexly interfingered with deep-sea sediments. These volcanics rocks occurred in an extensional geodynamic context (Albian-Santonian) generated by the drifting of the Iberian plate with respect to the European plate (Castañares *et al.*, 2001).

The Mesozoic sedimentary rocks in the Eastern North Pyrenees underwent a high temperature-low pressure metamorphism. Metamorphic rocks crop out in a narrow east-west trending belt called the North Pyrenean Metamorphic Zone (NPMZ), 0.5 km wide and about 300 km long (Fig. 1). The NPMZ is characterised by intense deformation related to extension, compression and transcurrent shear and by the occurrence of ultramafic bodies and alkaline magmatism. This Albian-Santonian metamorphism (110-85 Ma) is related to thermal anomalies coeval with the crustal thinning in the North Pyrenean Zone (Fig. 2). Crustal thinning and metamorphism developed during the sinistral transcurrent displacement of Iberia with respect to Europe (Goldberg and Leyreloup, 1990; Azambre *et al.*, 1991).

A large portion of the deposits in the eastern sector of the Cameros basin was affected by low grade and very low grade metamorphism (Fig 1). This was interpreted as a result of regional dynamo-thermal metamorphism coinciding with the filling of the basin (Mata *el al.*, 2001). Nevertheless, recent studies have defined this metamorphism as hydrothermal and alochemical (Alonso-Azcárate *et al.*, 1999). The age of the metamorphism is 106-86 Ma, i.e. from Late Albian to Coniacian (Fig.2).

The western margin of the Maestrat basin (Espadà Rangers), which underwent a very low-grade metamorphism (Fig. 1), displays high values of thermal gradient (Desert de les Palmes area, Penyagolosa sub-basin). Thermal gradients were calculated taking into account vitrinite reflectance measurements and burial depths (Fig. 2). These thermal gradient values exceed 30 °C/km, which is calculated by the stretching factor of the rift basin, the related surface heat flow and thermal conductivity values.

A hydrothermal event was identified in the Lower Triassic conglomerates (Buntsandstein facies) of the Espadà Ranges (Fig. 1), with salinity ranging from 15 to 22 wt.% eq. NaCl and moderate to high temperature (140–180 °C). Fluid flowed during Santonian times (84±4 - 85±3 Ma) probably through deep faults. Barite and Hg–Sb–

Cu–Ag sulfosalt vein type mineralizations formed owing to the mixing of these hot brines and sulfate-rich waters (Tritlla and Cardellach, 2003). Hg–Sb bearing deposits would indicate deep thermal conditions (Fig. 2).

A new hypothesis is proposed to explain the origin of these coeval phenomena of volcanics, metamorphism and thermal anomalies which affected the NE of Iberia during the Mid-Late Cretaceous. A hot spot which is currently located offshore opposite San Sebastian developed in relation to the opening of the oceanic North Atlantic and Bay of Biscay basins. This hot spot produced alkali basaltic volcanism in the Basque-Cantabrian and Central Pyrenean areas with a thinner crust and a basic deep pluton below the Iberian Chain with a thicker crust. This pluton gave rise to an anomalous mantle slightly denser (isostatic anomaly), a regional thermal event (with metamorphism, higher thermal gradients and Hg-Sb bearing deposits) and a significant aeromagnetic anomaly along the Iberian Chain.

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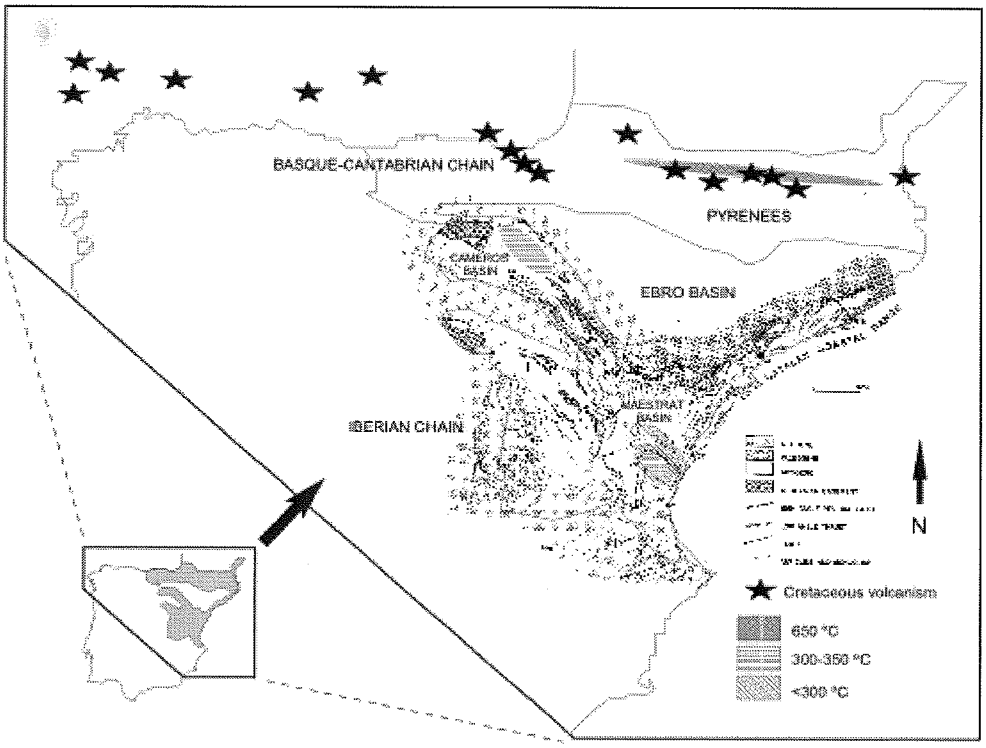

Figure 1.- Location map of the Eastern Iberia displaying a geological sketch of the Iberian Chain, the areas affected by Cretaceous volcanism, and the areas with diverse grades of metamorphism and anomalous thermal gradient.

	PYRENEES	CAMEROS BASIN	MAESTRAT BASIN			
			Penyagolosa	Desert de les Palmes	Espad□ Ranges	Espad□ Ranges
Thermal event	High temperature metamorphism	Low and very low-grade metamorphism	Hydrothermalism	Hydrothermalism	Very low-grade metamorphism	Hg-Sb deposits hydrothermalism
Age	110-85 Ma	106-86 Ma	Mid-Late Cretaceous?	Mid-Late Cretaceous?	Mid-Late Cretaceous?	84± 4 - 85±3 Ma
Vitrinite reflectance (%Ro)	---	---	0.82-0.98	0.7-0.8	---	---
Temperature (¼C)	650	300-350	120-134	119-127	300	140-180
Maximum burial depth (m)	---	---	1600	<2000	<4000	<4000
Thermal gradient (¼C/Km)	110-150	70	75-84	60-63	75	35-45
Reference	Goldberg y Leyreloup (1990); Azambre et al. (1991)	Casquet et al. (1992); Mata et al. (2001)	Caja (2004)	Mart'n-Mart'n (2004)	Mart'n-Mart'n (2004)	Tritlla and Cardellach (2003)

Figure 2.- Summary of the main parameters for the studied thermal events.

The environmental context of spatangoids (Echinodermata: Echinoidea) evolution in the Early and Mid Cretaceous.

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Mid-Cretaceous Oceanic Anoxic Events (OAEs) are characterized by deposition of black shale in the pelagic realm and by the demise of carbonate platforms. These events are assumed to reflect global changes in climate, chemistry and productivity of ocean waters related to submarine extensive volcanic activities (i.e. Ontong-Java and Kerguelen Plateaus). A link between OAEs and plankton evolution and turnover (speciation/extinction rate) has been stressed by several authors (Erbacher & Thurow 1997, Larson & Erba 1999, Leckie et al. 2002) but the underlying mechanisms remain unclear. On the one hand, increase in nutrient availability and/or modification of the upper water column should lead to an increase of marine productivity. On the other hand, an excess of CO_2 and low pH of sea water should involve a fall of calcareous plankton diversity (i.e. nannoconids near the OAE1a, nannoconids and calcified foraminifera for the OAE1b). Either increase in organic productivity, anoxia and low pH should have modified structure of benthic marine communities. Echinoderms are renowned to become very abundant in nutrient-rich sea bottoms, where they can form very dense aggregations (Hyman 1955). Anoxia of sea-bottoms increases the extinction risk of endobenthic forms compared to epibenthic organisms (Aberhan & Baumiller 2003). Therefore, attended effects of OAEs can be traced out from the fossil record by testing simple hypothesis of changes in benthic marine diversity as response to specific environmental changes.

Spatangoid heart urchins (Echinodermata, Echinoidea) are benthic marine invertebrates and constitute since the Eocene the most diverse subset of irregular echinoids (Kier 1974). Spatangoids are distinguished from other irregular echinoids by their burrowing activities. They are specialized to a more or less infaunal mode of life, burrowing in or ploughing fine sand and muddy sediments in which they feed by ingesting organic remains (Hyman 1955). The ability of several lineages for burrowing deeply into the sediment is understood as the key for their evolutionary success (Devriès 1960) as they could exploit new food resources formerly unavailable to other echinoids and could benefit from reduced competition and predation. Therefore, we can expect extinction peak and higher extinction risks for deep burrowing spatangoids due to anoxia during the OAEs.

Spatangoids originated in the lower Berriasian (Masrour *et al.* 2004) and diversified during the whole Cretaceous. Previous studies showed a continuous diversification trend of the group during the Cretaceous (Eble 1997, 1998, 2000, Villier & Eble 2004). This pattern suggests reduced effect of external forcing of fluctuating factors, such as variations in plankton productivity on large-scale evolution of spatangoids diversity. However, analyses undertaken at the generic and specific level showed a more contrasted pattern within the group (Villier 2001, Villier & Navarro 2004, Villier *et al.* 2004). The diversification was at some time subdued to the palaeogeographical history, to the settlement in new ecological niches and was associated to selective extinction peak associated to replacement of dominant clades. The first representatives (species of the genus *Toxaster*) were characteristic of offshore environments. Various derived forms colonized warm and shallow waters of shoreface environments, increasing the range of ecological niches occupied by spatangoids. During the interval Hauterivian–Aptian, the genus *Heteraster* was the most frequently encountered spatangoid throughout the Tethyan margins, occurring in the upper offshore and lower shoreface environments, mainly in orbitoline-rich marls and limestones (Rey 1972, Masse & Humbert 1976). *Heteraster* showed several phases of diversification correlated to the colonization of new palaeogeographical realms and the history of carbonate platforms. From the Hauterivian to the Barremian, the genus *Heteraster* diversified in the western Tethys. Its adaptive success was favored by morphological specialization for more efficient gas exchanges and burrowing abilities, and was coeval to the colonization of new ecological niches in shallow water platforms at the margins of Urgonian facies. *Heteraster* became much more diverse and widespread during the late Barremian and early Aptian. The development of Urgonian platforms led to a fragmentation of geographic ranges of species, favoring endemism and vicariance. *Heteraster* remained the most frequent and diversified spatangoid throughout the Aptian, however, new lineages differentiated in shallow waters by the end of the early Aptian, each with adaptive strategies to improve gas exchanges: the earliest member of a *Macraster/Douvillaster* clade (*Douvillaster convexus*) and of the Micrasteridae (*Epiaster polygonus*). Near the Aptian-Albian boundary, spatangoids experienced a second phase of diversification associated to the colonization of the American continent. Various independent lineages achieved this migration (at least four in *Heteraster*, one in *Macraster*, one in *Palhemiaster*). *Heteraster*, *Douvillaster* and *Macraster* remained the most common forms but the Albian was marked by the clear differentiation of the primitive representatives of the family Micrasteridae, Hemiasteridae and Schizasteridae – primitive members of all modern groups. Hemiasteridae (*Hemiaster*) specialized to muddy substrates of offshore environments and to cool shallow water carbonates whereas the family Schizasteridae (*Mecaster*, *Periaster* and *Polydesmaster*) adapted to shallow and warmer waters. In the late Albian, the genus *Heteraster* migrated to Japan and diversified there, whereas it declined elsewhere. In the lower Cenomanian, the Schizasteridae rapidly diversified and became a majority. At the same time, the diversity of the genus *Douvillaster* decreased and the genera *Heteraster* and *Macraster* became extinct. The demise of *Macraster*, *Douvillaster* and *Heteraster* might have been caused by competition with the diversifying Schizasteridae that evolved more efficient structures for gas exchanges and burrowing in shallow water environments. Late Cenomanian and further Cretaceous spatangoid communities were structured with Schizasteridae and some Hemiasteridae in upper offshore and shoreface environments, and Micrasteridae in mid shelf zone.

The diversification of spatangoids occurred in successive steps under the control of both biotic and environmental factors:

1 – The increase in taxonomic diversity seems linked to diversification of the occupied adaptive zones, the most crucial changes reflecting adaptation to warm waters through improvement of gas exchanges and to burrowing through modification of the locomotory apparatus, and differentiation of funnel-building tube feet. Therefore, clade replacement might be due to competition.

2 – During the early history of spatangoids (Berriasian to Albian), every colonization of new paleogeographical domains (southern and northern margins of the Tethys, American continent, Japan) is associated with a diversification, the species richness per genus being similar from a region to another (Villier & Navarro 2004).

3 – From the Barremian to the lower Turonian, high sea levels of the second-order (*sensu* Gradstein *et al.* 1994) are associated to the development of platforms and shallow water environments, which favors endemism and thus increases in species richness. Associated to regional tectonics, sea-level fluctuations also drive the opening and closure of migration routes (e.g. through the Central Atlantic).

Some of the OAEs occurred at (or close to) the time of changes in spatangoids diversity: OAE1a (early Aptian) at the date of differentiation of major groups, OAE1b (Aptian-Albian boundary) at the date of migration to the American continent; OAE1d (late Albian) at the date of migration to Japan. However, it remains unclear how OAEs and diversification or extinction of spatangoids could be related. If there is little evidence of a direct control of mid-Cretaceous OAEs and plankton productivity on spatangoids diversification, the associated climatic changes (sea water temperature) and sea level changes should be critical factors for turnover of species and regional extinction or diversification. Nevertheless, at a global scale and at a higher taxonomic level, OAEs do not lead to major diversity changes or selective extinction of deep burrowing forms.

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The Aptian and Albian series of the Vocontian basin (S.E. France) and Hokkaido (Japon): comparison of the litho-, bio- and chronostratigraphy.

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Introduction

The better understanding of a future warm greenhouse world relies notably on the increase knowledge of Cretaceous ocean-climate systems, as the mid-Cretaceous period (120 -90 Ma) is characterized by a huge production of oceanic crust and plateaus in the Pacific and Indian oceans, bringing higher levels of greenhouse gases and high poleward heat transportation, resulting in a global warming over this period (Larson, 1991). It resulted in a unique deep-ocean circulation and the expansion of widespread anoxic conditions (OAEs). Land sections across the Tethyan region (*e.g.* Erbacher *et al*, 1996), deep-sea cores from the Atlantic (*e.g.* Bralower *et al.*, 1994; Wilson & Norris, 2001) and the equatorial Pacific regions (*e.g.* Sliter, 1989) have been largely studied and correlated, whereas there are little informations about the same events in the North Pacific region.

This paper is a first attempt to present in parallel the Aptian-Albian series from the Vocontian passive palaeomargin (Friès, 1987; Bréhéret, 1995; Dauphin, 2002; Friès & Parize, 2003) with their time-equivalent from the Northeastern Asian active margin in central Hokkaido (Takashima *et al.*, 1997, 2001 and 2004). Both successions have been deposited in a relatively deep marine environment, characterized by abundant planktonic foraminifers and ammonites (in the upper Albian), allowing global-scale correlations based on bio- and also chimiostratigraphy.

The Aptian-Albian succession of the Yezo forearc in central Hokkaido (Japan)

The Aptian-Albian series correspond to the lower part of the Cretaceous Yezo group that is exposed in central Hokkaido (northern Japan). The Yezo group was deposited along a westward subduction margin of the Northeastern Asian continent during the Cretaceous; it consists of a 10000 m thick fore-arc sedimentary sequence of sandstones, mudstones and subordinate conglomerates. A very complex nomenclature has been used in the past and recent clarifications has led to the identification of six main units; the Aptian-Albian succession corresponds to the lower four units (Takashima *et al*, 2004):

- <u>Soashibetsugawa Formation</u>

Above the *in situ* volcanic and volcaniclastic rocks of the Sorachi Group (Berriasian to Barremian) that overlies directly the oceanic crust (ophiolites of the Jurassic Horokanai Formation), this unit consist of dark grey laminated mudstone with many intercalations of felsic tuff beds (10 to 30 cm thick, locally up to 7 metres thick). Corresponding to the basal formation of the Yezo Group, its thickness varies from 450 to 700 metres.
No macrofossils have been found in this formation. Radiolarians occur abundantly but no age-diagnostic species have been identified. Planktonic foraminifers appear rarely in the upper part, leading an Early Aptian age with the presence of *Leupoldina cabri* (Sigal); agglutinated benthic foraminifers such as *Bathysiphon* suggest with deep-sea trace fossils an abyssal environment.

- <u>Shuparogawa Formation</u>

The apparition of frequent intercalations of sandstone beds characterizes lithologically the base of the Shuparogawa Formation that overlies conformably the Soashibetsugawa Formation. It is mainly composed of alternating beds of thin turbiditic sandstones (Tb -Tc sequences with frequent sole marks, 10 to 50 cm thick, locally up to 1m thick) and dark grey mudstone. The entire Shuparogawa Formation is approximatively 1500 metres but varies from 800 to 2450

metres. Abundant slump beds are present especially in the lower part of the Shuparogawa Formation, locally named the Refureppu sandstone Member.
A key feature within the Shuparogawa Formation is the Kirigishiyama Olistostrome Member that represent an unique, up to 400 metres thick olistostrome containing huge allochtonous blocks of massive sandstone (< 40 m thick), alternating beds of sandstone and mudstone (< 20 m thick) and limestone (< 60 m thick). These reworked limestone bocks our raft consist of shallow water carbonates with corals, large foraminifers (*Orbitolina*), rudists and ooids fragments, contamined with chert, granite and sandstone pebbles. Traced out in the entire Hokkaido, it exhibits locally blocks that are exposed continuously over more than 3 kilometres!
Macrofossils have been identified in the upper part of the unit, with the presence of *Mortoniceras* cf. *geometricum* Spath, characterizing the upper Albian. Abundant planktonic foraminiferas include Aptian species with *Globigerinelloides barri* (Bolli, Loeblich and Tappan), G. duboisi (Chevalier), *G. ferreolensis* (Moullade), *Planomalina chenouriensis* and also Albian forms with *Ticinella primula* (Luterbacher), *T. roberti*, and the apparition of *Biticinella breggiensis* (Gandolfi) in the uppermost part of the formation. A significant hiatus spanning the late Aptian to the Lower -lower Upper Albian occurs between the base and the top of the Kirigishiyama Olistostrome, with the absence of the *bejaouensis* and *planispira* zones.
Lithological and benthic associations suggest that this formation was deposited on the continental slope or deeper, whereas the reworked limestone blocks have been derived from a shallow water environment.

- Maruyama Formation

The Maruyama Formation (in general 10 -80 metres thick) is composed of tuffaceous turbiditic sandstone beds. In the Tomamae area, the basal part of this unit consists of several hundred metres of thick-bedded, poorly sorted and clast-supported conglomerates. Theses conglomerates are mainly made of pebbles or boulders of rhyolite and subordinate mudstone and chert. This formation has been deposited during a short period characterized by huge felsic volcanic eruptions occurring along the margin.

- Hikagenosawa Formation

Above the Maruyama Formation, a very thick succession of dark grey mudstone is developed and reaches from 1900 up to 2600 metres in thickness. This Hikagenosawa Formation exhibits also thin-bedded felsic tuffs and distal turbiditic sandstones showing Tc-Te divisions. In the middle of this thick unit, the Kanajiri Sandstone Member composed of thick-bedded sandstones and conglomerates that have been traced out regionally. Ammonites and inoceramids becomes common leading to a excellent age assignment for this formation that span the late Albian to Middle Cenomanian interval with the presence of *Mortoniceras rostratum* (Sowerby), *Mariella bergeri* (Brongniart), *Mantelliceras saxbii* (Sharpe) and *Cunningtoniceras cunningtoni* (Sharpe). Planktonic foraminifers are abundant with *Biticinella breggiensis* (Gandolfi), *Ticinella subticinencis* (Gandolfi), *Rotalipora appenninica* (Renz), *R. globotruncanoides* Sigal and *R. cushmani* (Morrow) indicating a Late Albian - Late Cenomanian age (Nishi *et al.*, 2003).
Benthic assemblages suggest that this formation was deposited in the lower part of the upper bathyal zone under relatively oxygenated conditions.

The Aptian-Albian succession of the Vocontian palaeomargin (S.E. France)

The Aptian and Albian series of the French South-East basin consist of several hundred metres of siliciclastic to marly relatively deep-water (external shelf to lower bathyal zone) deposits that have been preserved from the Vocontian palaeomargin, which represents an extension of the Tethysian Ocean.

These series are organized into 9 sequences:

- the first four of them (Ap1 to Ap4) correspond to the Aptian stage and have been largely described by Friès & Parize (2003). The Aptian interval is characterized by the abundance of a wide range of gravity-driven deposits (slumps, debris flow deposits, turbidite packages and massive sandstone). The resulting model for the Vocontian Aptian slope systems represents an alternative to the "classic" Exxon delta-fed, mud-rich model.
- the upper five (Al 1 to Al 5) correspond to the Albian stage (Parize *et al.*, 2003). They are characterized by a limited number of massive sandstone packages and the absence of muddy-dominated gravity-driven deposits.

The detailed internal organization knowledge is based on: (1) a important number of 'key' lithological markers (such as blackshale levels, ash beds and up to 100 metres thick slumps deposits that are of basin-scale extension and thought to be synchronous throughout the slope domain; (2) detailed biostratigraphy, based on abundant macrofauna (ammonites and inoceramids) and microfauna such as benthic and planktonic foraminifers; (3) a detailed cyclostratigraphic analysis calibrated with carbon and oxygen isotopes curves; (4) absolute datations based on glauconites.

Conclusions

Many differences separate the Vocontian and the Yezo basin and not only the geographical setting: thickness, abundance of volcanics, lack or presence of blackshales... Despite the absence of blackshale within the Yezo Aptian and Albian succession, an integrated approach combining bio and chimiostratigraphical markers has allowed a tentative correlation with Tethyan and Atlantic events.
In order to improve these correlations the comparison between the two successions (French and Japanese) is of utmost interest as it provides new insights to the better understanding the majors events that characterize the mid-Cretaceous period: (i) anoxia a global event ? (ii) importance and effect of the volcanic activity within the marine deposits (iii) impact of the plate tectonic activity ?
Such an integrated approach is necessary to understand the major events that have affected the Earth during this critical "greenhouse" period, in order to have a more predictive model for the Present time

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ALBIAN DEPOSITIONAL SEQUENCE RECORD AND ASSOCIATED EUXINIC FACIES IN A PLATFORM-BASIN TRANSITIONAL ZONE: CENTRAL TUNISIA

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Key words: depositional sequences, facies distribution, euxinic facies, organic para-sequences, platform/basin transitional zone, Albian, Kasserine region, central Tunisia.

1- Introduction

During the Late Cretaceous interval, Tunisia was a part of the southern Tethyan margin which included a large central platform cut-up by NW-SE to E-W major faults into a series of blocks downstepping northward to open marine basin (*Tunisian trench*), whereas toward the south it is connected to the littoral *Saharan platform*. The Kasserine area (central Tunisia) which extends -since at least the Aptian- on a southern resistant block and a northern subsiding one separated by the E-W M'rhila fault (Touir, 1999; Bismuth et al., 1993) is one of the best settings in central Tunisia where the platform/basin transition can be studied, notably in the Albian outcropping records. In this region, the Albian deposits include four depositional sequences (*sensu* Vail et al., 1977) which are onlaping successively - southward - the already exposed Late Aptian carbonate platform – so called *Serdj* platform- the karstified and more or less truncated surface of which marks a regional unconformity correlatable with the 107.5 MA global sea-level fall (Haq et al., 1988; Hardenbol et al., 1998). The Albian deposits show particularly several black shale levels arranged into two main units respectively called *Allam Member* (Middle Albian) and *Mouelha Member* (Late Albian) which are regarded to be major source-rocks in Tunisia (Saïdi & Inoubli-Bekir, 2001; Troudi & al., 2002). Vertical distribution of total organic carbon (TOC) along these organic-rich levels determines several organic para-sequences which are superimposed to calcilutitic ones. In order to elucidate the geodynamic framework in which the Albian sequences have taken place while specifying the main controlling factors having led in particular to occurrence of the associated euxinic facies, the present paper aims to characterize these sequences on the basis of detailed analysis and distribution of the different Albian facies from survey of five key-sections (Fig.1) carried out along the study area from basin to platform settings. The associated sequence boundaries (i.e. unconformities) were defined from field mapping of the same area.

2- Albian depositional sequences

Examination of Albian deposit stacking pattern as well as the main associated unconformities from the subsiding block (basin) to the resistant one (platform) while taking into account both biostratigraphical data of the study area (Touir et al., 1989; Zghal et al., 1996) and global eustatic chart (Haq et al., 1988; Hardenbol et al., 1998) has led to define four depositional sequences which were differently recorded across the transitional zone (Fig.1).

2-1- The Early Albian sequence

The oldest Albian depositional sequence (100m) which is mainly Early Albian (*Hedbergella planispira* zone) in age (Zghal et al., 1996) is only recognized within the subsiding block next to the M'rhila fault where it lays on the previously exposed surface of the Late Aptian carbonate platform (*Serdj platform*). Volumetrically, the sequence is mainly represented by the transgressive interval that determines a carbonate shelf facies (*sensu* James and Mountjoy, 1983; Read, 1985) formed by thinning and fining-upward mudstones and shale rich in both benthic and planktonic foraminifers, as well as sponge spicules and fine-grained detritic quartz. The regressive phase is illustrated by massive dolomites bearing scattered coral and sponge individuals in growth position. The sequence is bounded above by a ferruginous hard-ground which is abruptly overlain by marls and shale.

2-2- The Middle Albian sequence

This sequence is the thickest one (> 800m), however it stretches only over few kilometres southward on the emerged uplift-block border with less than 50m in thickness. The sequence is mainly Middle Albian in age (*Ticinella primula* zone) on the uplift-block while it goes down in the low Middle to Early Albian within the subsiding one; its lower boundary which corresponds to a concordant surface within the basin block passes into the surface still exposed of the *Serdj* carbonate platform toward the uplift block border. In the first domain developed mud-rich basin facies containing radiolars and planctonic foraminifers which grades upward to carbonate shelf succession dominated by black shales (TOC 0.5 - 2 %: *Allam Member* source-rock) indicating a low-energy environment where the water column was periodically stratified, with anoxic conditions at the bottom. This organic-rich succession shows many organic para-sequences (Figs.2) which are superimposed to calcilutitic ones and locally interrupted by reworked material brought from the neighbouring platform border; such features likely reflect abrupt and impulsive variation of both subsidence rate and sea-level rise. Along the uplift block border has taken place a coralline algae fringing-reef - also Middle Albian in age - which is locally relayed by rudist and serpulid-bearing limestone.

2-3- The Late Albian *s.s.* sequence

The third Albian depositional sequence -Late Albian s.s. (*Biticinella breggiensis* zone) to low Early Vraconian (*Planomalina buxtorphi* zone)- does not extend farther southward than the previous one, because of slow-subsidence rate on the uplift block as thickness variation of deposits between the platform block (50m) and the basin one (270m) testifies. Moreover, deposits illustrate toward the basin a carbonate shelf facies where thinning and fining-upward calcilutitic para-sequences are associated to pyrite-rich black shales (TOC 2 - 3 %, *Mouelha Member* source-rock) also arranged into organic para-sequences (Figs.2,4) then the sequence ends by an outer-shelf facies composed of marl/limestone para-sequences rich in benthic fauna-and sponges spicules, whereas on the platform border occur high-energy ooid-sand bars rich in algae debris and glauconite which lay on the preceding algae build-ups. The upper sequence boundary is traced on the resistant block border by a subaerial erosional surface and in the subsiding one by a ferruginous hard-ground probably due to either sedimentary break or slow sedimentation rate.

2-4- The Vraconian sequence

The uppermost and youngest Albian sequence which is mainly Vraconian in age (*Planomalina buxtorphi* zone, in Touir et *al.*, 1989; Zghal et al., 1996) extends considerably southward compared to lower sequences while covering the surface remaining still exposed of the Late Aptian *Serdj* platform (Fig.1) and stretching toward southern Tunisia on the littoral *Saharan platform*; its thickness is maximum (150m) on the platform/basin boundary while it decreases both southward (30m) and northward (50m) due to prograding sedimentation. On the basin block the sequence is bounded both below and above by concordant surfaces marked by sharp transition between shallower and deeper water facies whereas on the platform block the lower sequence boundary consists of an erosion surface (unconformity) that becomes confound toward the south with the *Serdj* platform exposed surface, while becoming increasingly weathered and truncated. Above, the Vraconian sequence is bounded by a burrowed hard-ground where a sharp transition from shallower to deeper-water facies occurs.

The youngest Albian sequence can be distinguished from the lower ones not only by its considerable geographic extension on the Late Aptian platform but also by the wide facies-range it provides depending notably on local tectonic activities and structural framework controls. Indeed, from basin block to platform one occur respectively (i) outer-shelf to basin facies formed by marls and mudstone intercalations rich in planktonic foraminifers and calcispheres as well as glauconite (ii) outer-shelf facies with marl/limestone para-sequences containing well-preserved both benthic and planktonic fauna, as well as glauconite and phosphates (iii) rudist-bearing organic shoal and (iv) confined muddy lagoons where formed palygorskite and euxinic sediments associated to reworked material brought from this neighbouring shoal. While going farther to south, where the Late Aptian *Serdj* platform is already cut-up into a series of grabens, there are also muddy hollows (*i.e.* south of Jebel M'rhila, Jebel Semmama) which are nevertheless less confined than that adjacent to the organic shoal on the platform border. The sequence ends with a shallow-water prograding carbonate ramp that filled the whole preceding muddy hollows and extended far to north within the basin domain.

3- Eustatic and local tectonic controlling factors

While comparing the Albian depositional sequences already defined in the study area to the third order global eustatic fluctuations (Haq et al., 1988; Hardenbol et al., 1998) while considering the biostratigraphic data of the study area (Touir et al., 1989; Zghal et al., 1996) especially the Early Albian p.p. hiatus, it appears clearly that these sequences as well as their respective boundaries are rather correlatable with those of Haq and others (1988), precisely UZA-1.3 to UZA-2.1 (Fig1). In particular, the most prominent karstified and more or less truncated surface of the Late Aptian *Serdj* carbonate platform displays a major unconformity which is largely recognized all over the study area and can be then roughly equivalent with the major magnitude sequence boundary SB 107.5 MY according to the global eustatic curve. On the other hand, the Middle Albian sequence -which is by far the thickest one- shows however a little extent of its coastal onlap in spite of high amplitude of the Middle Albian sea level rise. Such a situation can be related therefore to high subsidence rate within the basin block which should have been not only thermal-related but also of tectonic origin, all the more since local syn-sedimentary tectonic activities during the Late Albian are largely described and documented yet both in study area (Bismuth et al., 1993; Boukadi et al., 1992) and whole central Tunisia (Chihi & Ben Ayed, 1987; Ben Ayed, 1993; Bouaziz et al., 2002). So be it, subsidence rate must be remarkably higher in the basin block where subsidence associated to sea level rise resulted in creation of more accommodation space and stratification of water column having led to euxinic facies (i.e. black shales). Furthermore, local tectonic activities were also responsible for differentiation and geographic distribution of different Albian facies notably those of the Vraconian sequence. Sequence boundaries (*i.e.* unconformities) were also controlled, in addition to sea level changes, by local tectonics seeing that concordant surfaces in the subsiding block are relayed by erosional truncated surfaces (unconformities) on the uplift one.

Tectonic manifestations seem to have been rapid and impulsive as testifies the vertical distribution of total organic carbon (*i.e.* organic para-sequences) along black shale levels within the basin domain; furthermore, occurrence of reworked material (olistolithes) brought from the adjacent platform border within the basin also reflects impulsive fluctuations of both subsidence rate and sea level rise.

4- Conclusions

The sequence stacking of Albian outcropping deposits was notably controlled by relative sea-level fluctuations, whereas geographic extension, sequence boundaries and associated facies distribution were depending both on local tectonics and eustasy. Particularly, the Albian organic-rich levels that display source-rocks occurred preferentially towards the late transgressive stages of the eustatic cycles, especially when impulsive subsidence and sea-level rise can be coupled.

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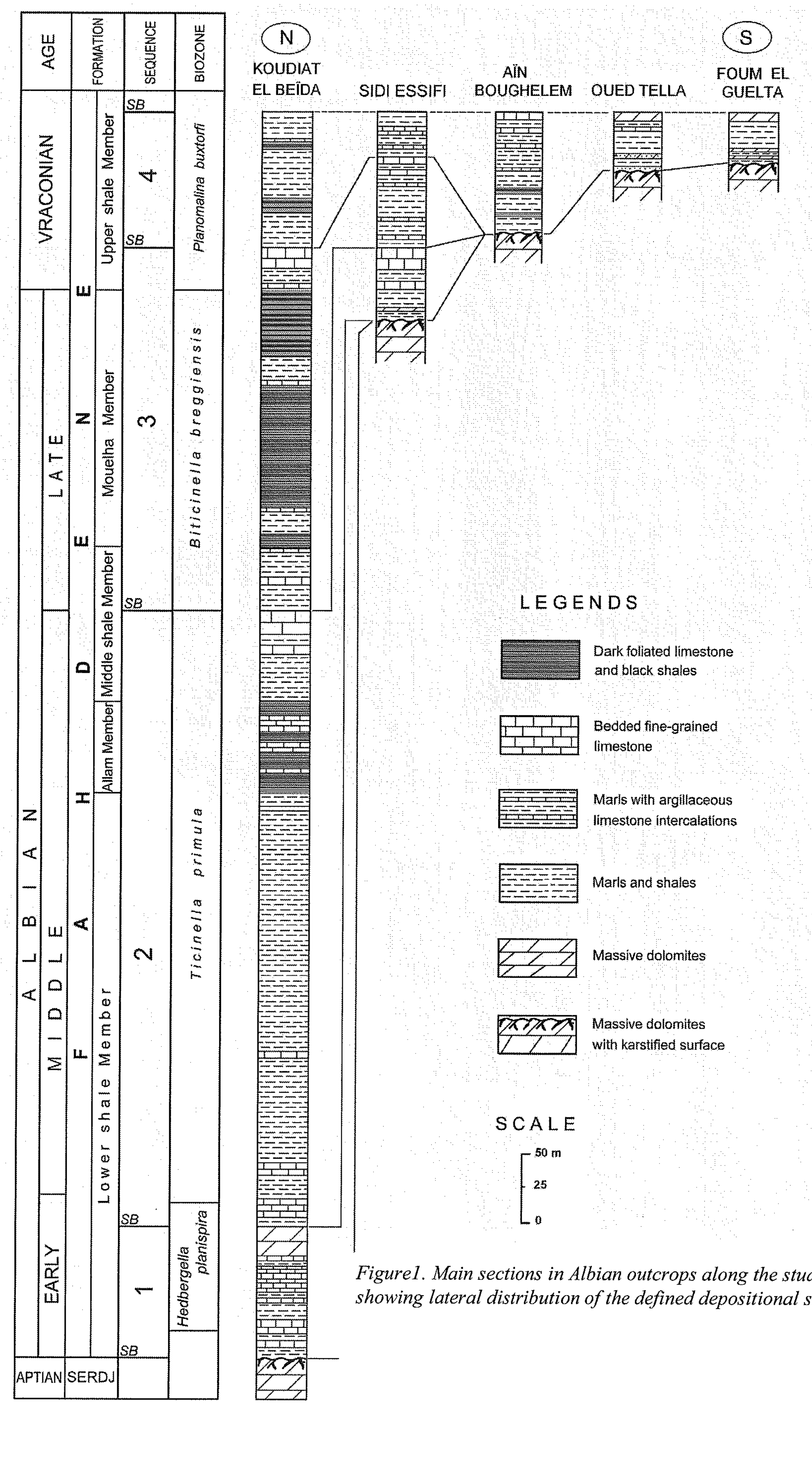

Figure1. Main sections in Albian outcrops along the study area, showing lateral distribution of the defined depositional sequences.

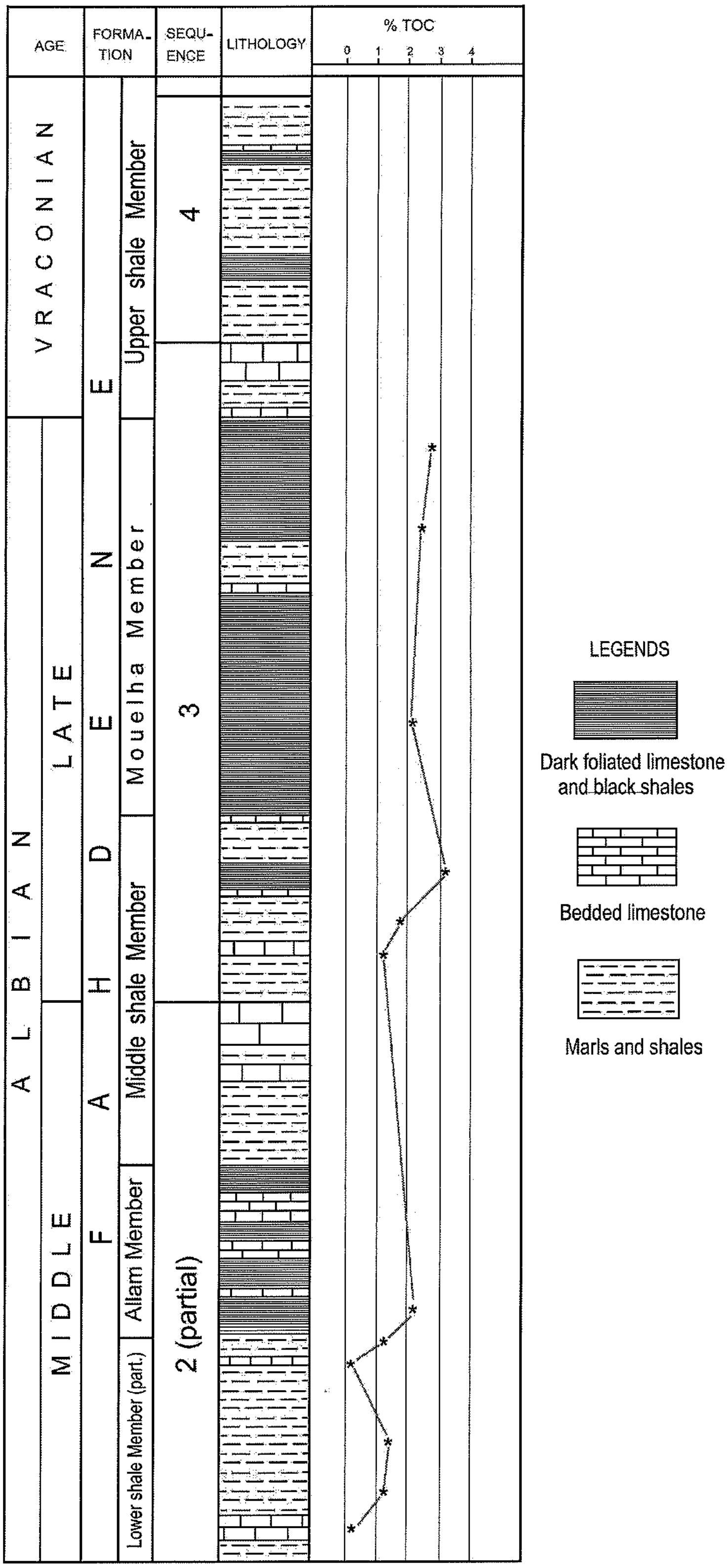

Figure2. The Koudiat El Beïda section (basin domain), showing the main black shale units and distribution of respective total organic carbon content (TOC).

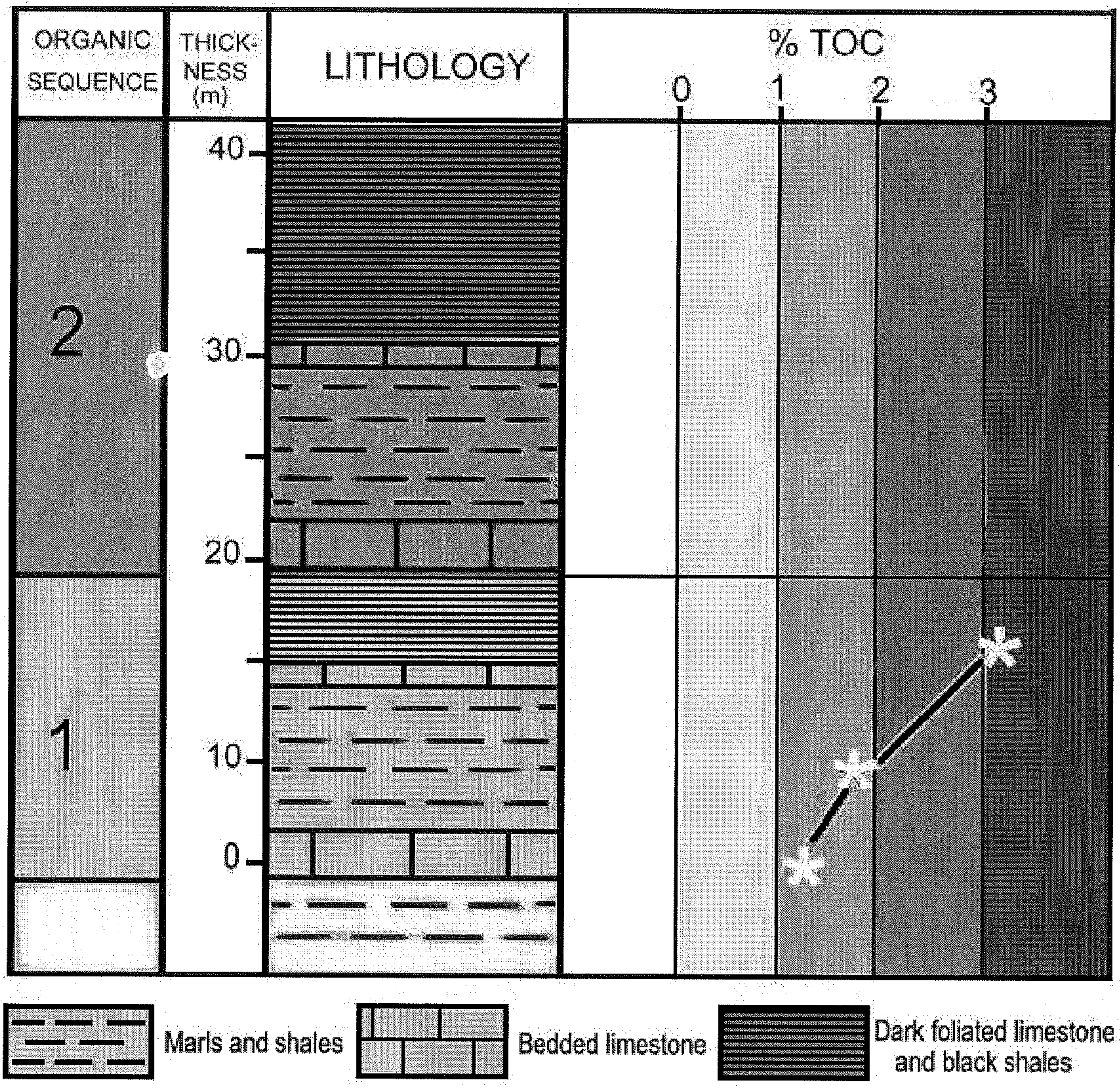

Figure3. Schematic illustration of the TOC amount evolution along the Allam Member, showing an organic parasequence, Koudiat El Beïda section (basin domain).

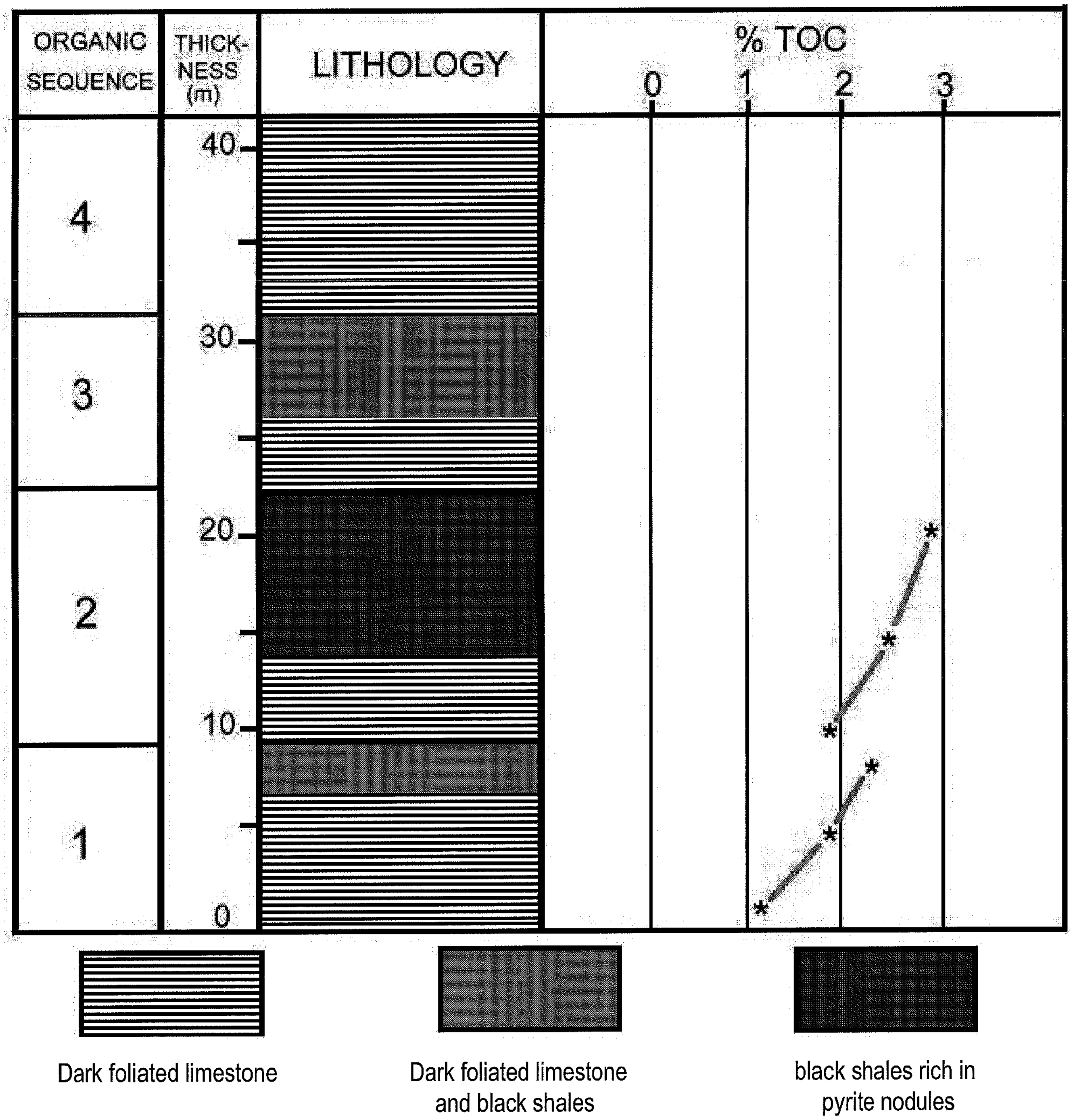

Figure4. Organic para-sequences along the black shale unit of Mouelha Member (Late Albian), Koudiat El Beïda section (basin domain).

External magnetic forcing and cosmic radiation during the Cretaceous Normal Polarity Superchron

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Cosmic radiation (CR) is considered an important factor modulating atmospheric physics particularly the cloud formation and, therefore, it can play a role in climatic changes. The strength of this type of electromagnetic radiation received at Earth is influenced by the magnetic fields surrounding us. Three magnetic fields (galactic, solar, Earth's magnetic field) are to be considered here. The stronger the solar - or geomagnetic fields the more efficient is the deflection of cosmic ray particles. Galactic magnetic fields control the distribution of CR in our galaxy.
During the Cretaceous all three magnetic fields appear to have been at a mode allowing particularly few CR to reach our planet. This should have in general decreased the production of clouds by CR-induced nucleation, decreasing albedo and thus supporting global warming. In this paper the role of the Cretaceous Normal Polarity Superchron reflecting a strong geomagnetic field, and related astrophysical phenomena are discussed. Interestingly, the Earth's magnetic field repeatedly switched between two modes, the „reversing mode“ (frequent polarity reversals) and the „superchron mode“ (tens of Million years long phases of non-reversal) at a period similar to that of the travel time of the solar system between the spiral arms of the galaxy (Wendler, 2004). Moreover, at millennial timescales, Earth and Sun seem to vary synchronously in their magnetic field strength. This raises three major questions: Is there a long-term galactic forcing of Earth's magnetic field? Does the Sun experience externally-forced magnetic activity modes in phase with Earth? Is there a causal relationship between the solar system's magnetic field modes and Earth´s climate modes?

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Oceanographic changes and biotic events during times of Cretaceous ocean plateau formation

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The Aptian-Turonian interval represents the time generally considered to be the apogee of the Cretaceous greenhouse world; a warm interval marked by low equator-to-pole temperature gradients and an all-time Phanerozoic high of global sea-level. Within this interval there are clearly climatic variations with clear evidence for polar glaciation around the Aptian-Albian boundary and a Cretaceous peak of global temperatures around the Cenomanian-Turonian boundary.

Oceanographic changes at this time were dramatic with substantial redox fluctuations from the extremes of the Selli and Bonarelli oceanic anoxic events (OAE1a and OAE2 respectively) to under-appreciated marine red-bed events: "oceanic oxic events". The anoxic events are regarded to have caused perturbations of the carbon cycle, with the enhanced burial of marine organic matter producing positive excursions of $\square^{13}$C ocean-atmosphere record. However, in detail the correspondence between positive excursions and organic-rich deposition is not seen. For example, both OAE1a, and OAE1d (the Breistroffer event of the Late Albian) see $\square^{13}$C values begin to rise late in the history of anoxic development and peak substantially after the termination of the events. In fact, the $\square^{13}$C record shows closer correspondence with the eustatic sea-level curve suggesting that changes in the area of shelf sediments is a more important control of the amount of organic C being buried globally. That the anoxic events coincide with marine transgressions probably explains the origin of the approximate correlation with marine anoxia.

The early history of the Selli event is marked by a rapid, high amplitude (2 ‰) negative excursion of $\square^{13}$C values that is widely regarded as a signal of gas hydrate dissociation and the release of methane into the oceans and atmosphere. The resultant warming trend may be, in part, due to this release event although comparable temperature trends and oceanic phenomena are seen during the Bonarelli event when there is no evidence for gas hydrate release. Conditions in the preceeding Cenomanian Stage may have been too warm to allow build up of an appreciable reservoir of hydrates with the result that the end-Cenomanian thermal maximum did not destabilise any significant amounts of hydrates.

Despite the substantial temperature and redox extremes of the Aptian-Turonian interval, there was no biotic crisis deserving of the epithet mass extinction. Nonetheless, there are several crises that provide intriguing insights into the nature of the extreme climates. Thus, equatorial temperatures in the Cenomanian-Turonian interval may have been so extreme (sea-surface temperatures > 30°C) that marine life was essentially not sustainable. This probably accounts for the demise of carbonate bioproductivity on oceanic islands as they drifted across the equator in this interval. As a result drowned guyots were established that are still present today in the Pacific. The flooding of anoxic waters into the epicontinental seaways also ensured the extinction of many marine invertebrates, although not on the scale of the end-Cretaceous losses. In contrast the fortunes of planktonic foraminifera was one of rampant speciation in the Cretaceous greenhouse world, with the exception of a steep diversity decline in the late Aptian. This interval witnessed both cooling and (glacioeustatic?) regression and suggests oceanic changes associated with cooling were more significant for this group.

The oceanic anoxic events witnessed dramatic changes of plankton composition. Generally surface-water carbonate productivity was suppressed whilst radiolarian populations flourished, although paradoxically many radiolarian species went extinct during the OAEs. The Selli Event is immediately preceeded by a well-documented "nannoconid crisis". This temporary decline in the abundance of these calcite-secreting phytoplankton that probably reflects surface-water acidification, which may partially reflect the water-column oxidation of methane released from hydrates.

So how do these changes relate to the oceanic volcanism of this interval? The clear correspondence of timing between OAEs and oceanic plateaus (e.g. Ontong-Java/Selli, Caribbean/Bonarelli) clearly invites cause-and-effect hypotheses. The possibility of oceanic fertilisation, principally by iron, has been proposed as a mechanism for increasing oceanic productivity, and thus biological oxygen demand within the mid-water column. However, it is difficult to envisage this fertilisation occurring very far beyond the immediate proximity of the volcanic site. More "global" mechanisms may relate to the effects of volcanic CO_2 release and global warming. All the OAEs and associated planktonic changes appear related to substantial changes in water column structure and especially the break-down of water column stratification to the point where thermal gradients in the water column became minimal. Understanding the origin of this extraordinary oceanic situation lies at the heart of the volcanism-climate-ocean link.

POSTERS

ALBIAN PALEOGEOGRAPHY AND FORAMINIFERS IN WESTERN SIBERIA: EVIDENCES OF FIRST MID CRETACEOUS MAXIMAL TRANSGRESSIVE EVENT IN NORTHERN CENTRAL EURASIA

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Marine Albian sediments in the Western Siberian region have been formed as a result of large ingression of the Paleo-Arctic ocean far inland Siberian platform; its are underlayed and covered by mainly continental deposits. The area of epicontinental Albian West-Siberian inner sea at the moment of maximal marine transgression reached 170 million square kilometers, that is significantly exceeded the sizes of Neocomian seas.

West-Siberian marine basin belonged to the Arctic paleogeographic realm, which included during Cretaceous epoch all recent Arctic territories (islands and archipelagoes, lands and shelf margins – approximately up to 50-60 N degrees of modern latitude – after Zakharov et al., 2003). Albian West-Siberian inner sea has been bounded by a land in the south, the east and the west, and is opened into Paleo-Arctic ocean in the north (cf. fugure). Shape, sizes, configuration of coastal line, physical and chemical parameters of this sea essentially changed during Albian time.

Albian marine deposits in Western Siberia are combined into the Khanty-Mansyisk regional lithostratigraphic horizon, presented predominantly by black-colored silty-clayey rocks of Khanty-Mansyisk Suite. The Khanty-Mansyisk horizon and same-named suite are characterized by several marine fossil groups (like ammonites, bivalves, ostracodes, etc.), and foraminifers are the most geographically widespread of them. Consecutive replacement of foraminiferal associations in the time and space reflects the allocation and changes of lito-biofacial environments during Albian time. First appearances of Albian faunas in the West-Siberian sea in terminal Aptian - initial Albian is connected with transgression of Timan-Pechora East-European boreal sea into Northern West Siberian regions including Northern Trans-Urals area (Bulatova, 1976).

In the beginning of Early Albian the geographic distributions of representatives of fossil genera *Cleoniceras* (ammonites), *Cyprina*, *Nucula*, *Barbatia*, *Cirsocerithium*, *Protocardium*, *Camptonectes* (*Mclearnia*) (bivalves), foraminiferal assemblage with c *Ammosiphonia nonioninoides*[*] (or with *Gaudryina tailleuri*)), have been limited by Berezovo, Schaim areas, southern part of the Polui-Yamal area, and narrow gulf-like belt along North-Eastern Urals. This early Early Albian association of foraminifers contain 27 species, including species with agglutinated or calcareous tests. Specific composition of such assemblage is rather similar to the Western Kazakhstan and Russian platform Aptian foraminiferal associations (Zakharov et al., 2000). It is quite possible, that the free faunal exchanges between of Pri-Caspian, North-Eastern Russian platform, Russian shelf of Barents sea and West Siberia basins are realized due to passage, was existed along western slope of the Urals mountain system during Barremian–Early Albian (Bassov et al., 1997).

Late Early Albian fossils are significantly more widespread. This faunal composition represented by representatives of *Grantziceras*(?), *Subarcthoplites* (ammonites), *Mactra*, *Panopea*, *Ampollospira*(?), *Anthomya*, *Mytiloides*(?), *Tellina*, *Pecten*, *Nuculana* (bivalves), and foraminiferal assemblage with *Ammobaculites fragmentarius*. Maximal area of distribution of foraminiferal association with *Ammobaculites fragmentarius* shows the short-time peak of Early Albian boreal transgression. For the northwestern areas of Western Siberia it are characteristic the most various foraminiferal associations, where species list includes 40 agglutinated and calcareous species. Notably more poor associations distributed on territories, which adjoined to the eastern slope of Middle Urals from east, where calcareous forams are rare. Index-species *Ammobaculites fragmentarius* consists around half of common specimens number. The peculiarities of such distribution of forams may indicate the existence of physical-geographic sublatitudinally placed ecological barrier, which put obstacles in the way of penetration of calcareous forams in direction to the south-west. Most probably cause for this phenomena is oxygen deficit in bottom layers of water column in south-western areas of Albian West-Siberian basin. South-western district of Early Albian sea is characterized by significant prevalence of agglutinated foraminiferal genera *Miliammina*, *Verneuilinoides*, *Bathysiphon*, *Hyppocrepsina*, *Hyperammina*, *Reophax*. This composition of foram associations could be interpreted

[*] Here and below is named just only index-species of biostratigraphic foraminiferal zones.

as reflection of sharp change of saline regime, also of quiet hydrodynamics and extreme shallow environment. Only eurihaline and resistant forams were able to overpass the physical-geographic barrier in the view of lowered salinity. From over hand, shallow water foraminiferal associations inhabited vast territory of eastern part of the West-Siberian basin (Ust'Enisey, Turukhan, Ust'Balyk, Surgut, Megion, Vakh, Ust'Sulga, Pudino areas).

In Mid Albian time the territory of basin was reduced up to 108 million square kilometers, as a result of the dewatering of eastern Omsk-Larjak area. Mid Albian fauna is characterized by low specific diversity. On the most part of territory are found out the assemblage of agglutinated forams with *Verneuilinoides borealis assanoviensis*, in which the representatives of genera *Verneuilinoides*, *Eggerella* and *Ammosiphonia* sharply dominate, but secretory individuals are very rare. It is supposed, that this association existed in conditions of the low-salinity freshened basin. Peripheral margins of Mid Albian basin (Tyumen city, Petropavlovsk city areas) were occupied by impoverished shallow astrorhizid association of forams.

The stable normal marine regime continued to exist in the north of basin (to the north of modern Polar circle), where among macrofauna are found out ammonites *Pseudopulchellia* and marine bivalves *Integricardium*, *Inoceramus*, *Entolium*, *Nuculana*, also forams of assemblage with *Ammobaculites fragmentarius*. This foraminiferal association have high taxonomic diversity and includes numerous rotaliid forams – species with calcareous shell.

In Late Albian the total area of West-Siberian basin was sharply reduced, and the degree of freshening its waters has increased. In the territories adjoining to Northern and Polar Urals are found out the foraminiferal assemblage represented by a small number of species, among them *Verneuilinoides borealis assanoviensis* dominates. Only in the Poluy-Yamal structural-facial area Late Albian fauna had high taxonomic diversity (ammonites, bivalves, rotaliid forams), that reflects its inhabitation in conditions of normal marine salinity.

West-Siberian foraminiferal associations of late Early Albian, Mid and Late Albian have distinctly expressed northern origin. The great similarity in composition and structure of associations is observed between same-age foraminiferal fauna from Western Siberia, Alaska and Arctic Canada. It is supposed, that expansion of marine basin into Western Siberia during early Albian has led to occurrence of steady connection with the Arctic epicontinental basins of Northern America.

For Cretaceous Paleo-Arctic Ocean it was inherent the cyclicity, conditioned by general tectonic processes, development of relief, eustatic fluctuations of World ocean level. The last were especially evidently shown in transgressive-regressive rhythmics in internal epicontinental seas, and, in a little bit more smoothed form, in central parts of Paleo-Arctic Ocean. So, the Barents Sea shelf transgressive-regressive curve based on quantitative analysis of foraminiferal assemblages (Bassov et al., 1997) has elevation in Early Albian, two peaks in Mid Albian and one peak in Late Albian. This curve shape coincides with scheme of Alaska transgressive-regressive oscillations.

On North American continent (basin of Yukon River) the analysis of character of distribution of deposits, in view of their energetics and peculiarities of distribution of forams, indicates the intensification of marine regime for local Clearwater Sea (transitive interval from Aptian to Albian and the beginning of Early Albian), for Notikiwin Sea (early Middle Albian), the maximal peak for Joly Fou Sea (the ending of Middle Albian) and weak peak for Mowry Sea (Late Albian) (Chamney, 1978).

According to our data (Amon, 2005), Western Siberian Albian transgressive-regressive curve has similar shape of two-leveled transgressive cycle with the beginning on boundary between Aptian and Albian deposits, with the gradual intensification of marine regime and reaching of maximum in middle Early Albian, then gradual regress during Middle and Late Albian. This cycle is equivalent to integrated maxima of the Notikiwin, Joly Fou and Mowry Seas in internal Alaska.

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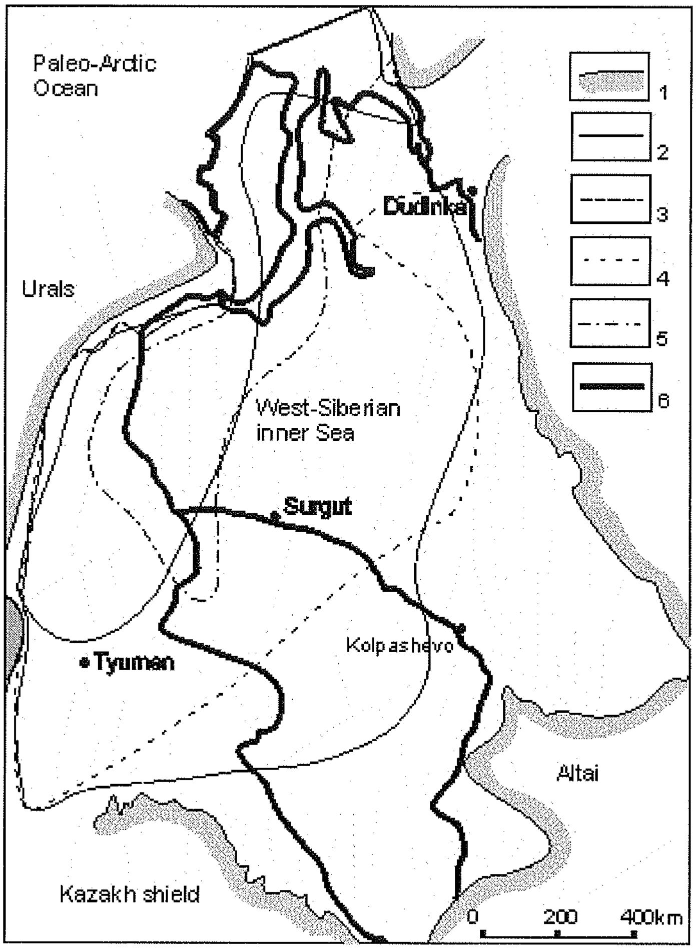

Figure. Configuration of the West-Siberian sea in Albian time.
1 – borders of sedimentary cover of Western Siberia. 2-6 – borders of marine basin: 2 – in the beginning of early Albian; 3 – in the ending of early Albian; 4 – in the Mid Albian; 5 – in the Late Albian. 6 – modern rivers and modern coastal line.

Record of Aptian – Albian relative sea level changes in karstic microcave fills. Example of the Vercors Massif – France.

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Subaerial exposure surfaces can occur on shallow marine carbonate platform. But, only sequence boundaries associated to wet climate, long enough time exposure and significant fall of sea level promote no-deposition, commonly erosion and diagenetic processes originating karst facies.

The rate of sea-level changes and the duration of stillstands at each sea-level position control both the distribution and the type of karst facies. At the beginning of sea-level fall, carbonates are early and partly cemented, hence a superficial epikarst can develop small sized centimetre to decimetre microcaves resulting either from marine bioerosion (gastropods, bivalves, blue-green algae,...) or early meteoric dissolution-enlarged, pre-existing porosity (shell molds, root molds, bioturbations, fractures,...). These primary microcaves will be enlarged by the development of karstification. Nevertheless a few of them can be preserved and record later changes in sea level as well in complex cavity fills as phases of dissolution and cementation. The process is available only for isolated centimetre scale microcaves if the same sequence boundary is used later as "intraformational unconformity", which controlled the development of vertically and laterally extensive karst porosity such as caves, caverns and dissolution enlarged fractures and faults.

This method was successfully applied on several Jurassic and Cretaceous microcave fills. The most significant example corresponds to 5 to 7 cm size microcaves that developed on the top of lower Aptian carbonate platform of Vercors massif (France) and then were episodically and partially filled up to Late Albian. It allows us to characterise up to 30 various diagenetic phases extended on 15 MY, showing up to 4 fall and rise of sea levels attested by paleontologic, sedimentologic and diagenetic data.

After the deposition of the last shallow-water carbonates of the Urgonian platform, successive sea level falls induced a karst development whose only small-sized cavities and fissures are still preserved. So appears a succession of cavity-filling deposits separated by erosion surfaces, evidences of 4 sea-level fall and rise cycles (Fig.1).

The first fall in sea level, linked to the earliest karstification, is early Aptian in age (Bedoulian), induced the emergence of the top of the cretaceous platform and produced incised valleys like the Rimets in Vercors Massif whose the depth implies that there was at least 50 to 60 m fall in sea level. The first transgression corresponds to the upper Orbitolina marls (*Palorbitolina*) at the top of the early Aptian. The second sea-level fall probably occurred during Late Aptian and is attested by the presence of green marls. The second transgression occurred during Gargasian (Late Aptian), but was only recently identified on outcrop (The Jarrands location).

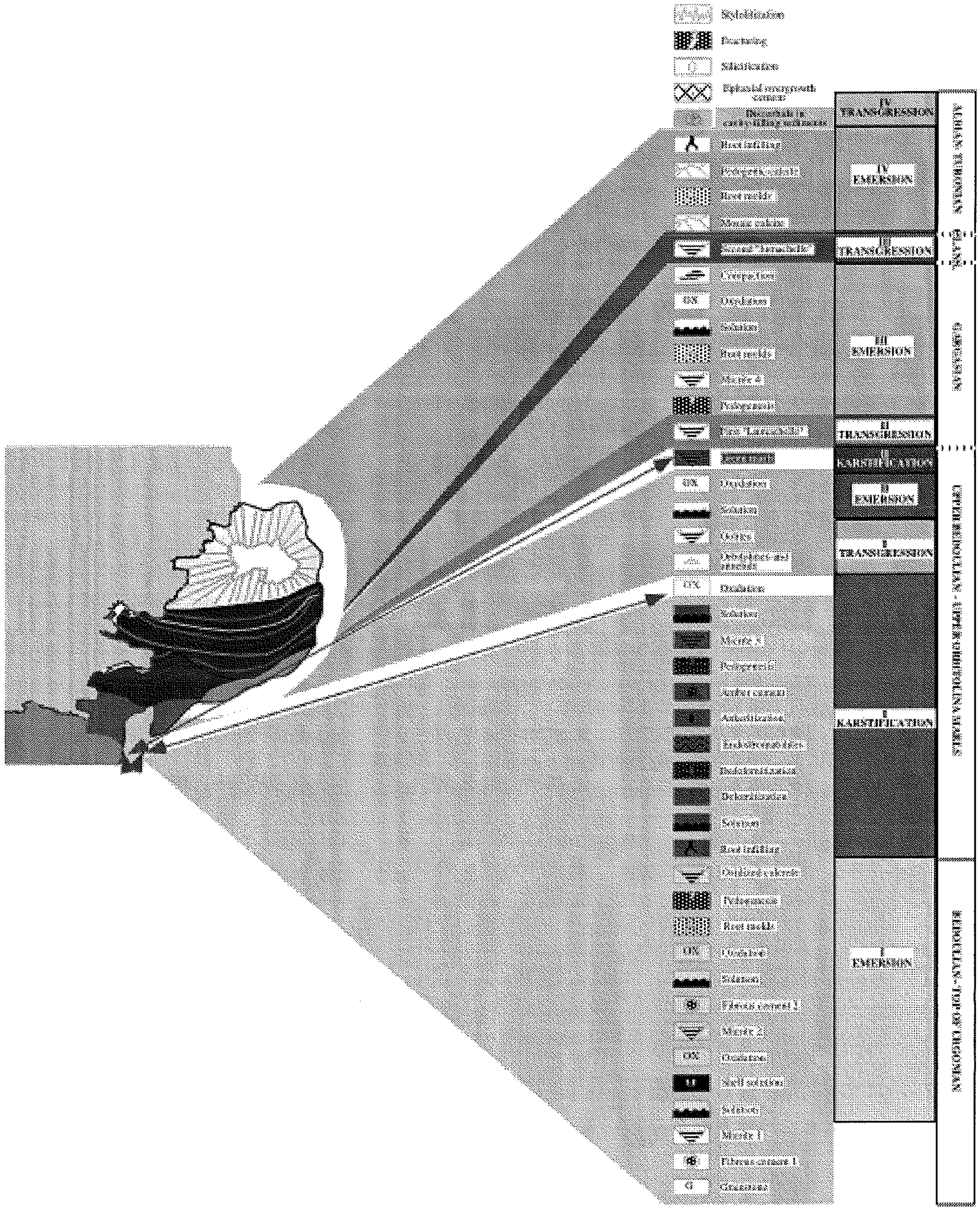

Fig.1: Diagenetic log showing the complex diagenetic history and the successive sea level change cycles linked to the Aptian emersion. Example of karstic centimetric cavities at the top of the Urgonian limestones from the Achard syncline (Vercors Massif – France).

It is recognised by a brown, brachiopod-bryozoan wackestone-packestone and called “First Lumachelle”. So, during a long time, these “Lumachelle” infilling was the only witness of the Gargasian deposits on the Urgonian surface.

The third fall in sea level is stratigraphically located at the Gargasian – Clansayesian boundary, near the top of Aptian, caracterized by new karstification processes and followed by the third transgression deposits represented by the “Second Lumachelle”, crinoid-bryozoan packstone – grainstone rich in glauconie and quartz. Two specific levels of sanstone and pure crinoid grainstone described in Jarrands are well preserved in these microkarstic caves. The last cycle of sea level change is associated withe the major fluctuations in sea level that occurred during the Cenomanian to Turonian. The sea level fall is attested by the presence if a vegetal cover (root molds and pedogenetic calcite *Microcodium*). This Albian - Turonian event is probably tectonic in origin and linked with the ante-Senonian folding. The further transgression is revealed by the presence of small foraminifers (Discorbids) trapped in the voids formed by roots.

THE EUTROPHICATION EVENT AT THE CENOMANIAN-TURONIAN BOUNDARY: A CAUSE FOR MASS EXTINCTION?

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INTRODUCTION

Cenomanian-Turonian sediments record major faunal changes and an increase in preserved organic matter. The second largest Cretaceous mass extinction took place at the Cenomanian-Turonian boundary. These changes, which took place simultaneously in different palaeogeographic settings, are interpreted to result from global oceanic processes (Schlanger *et al.*, 1987; Pederson and Calvet, 1990; Gale *et al.*, 2000). To date, no detailed studies have been undertaken to investigate these processes in the platform facies. The present study is an attempt to understand what happened in shallow-water platform settings during the Cenomanian-Turonian times, focusing on the Spanish Pyrenees. Previous studies of the area's excellent outcrops (Caus *et al.*, 1993; 1997) have allowed us to: a) reconstruct its depositional history, and b) establish detailed correlations between the shallow neritic facies, which contain abundant shallow-water benthic organisms, and the basin, talus (slope) or outer platform sediments, which contain pelagic fauna (ammonoids and planktonic foraminifera).

GEOLOGICAL SETTING

The study area (fig. 1) is situated in the South Pyrenean Upper Thrust Sheet Unit (Muñoz, 1985). It formed a part of the Iberian continental margin that was displaced southward during Late Cretaceous-Oligocene times. Palaeogeographically, the area consists of an expanded and subsiding basin in the north-northwest and a more stable platform in the south.

The main stratigraphic Cenomanian-Turonian basinal units, from bottom to top, are:

1. Marls and marly limestones of the Sopeira Fm (Mey *et al.*, 1968). This unit has a maximum thickness of 350 m, and is interpreted to have been deposited in an homogeneous subsiding basin. The age of the Sopeira Fm ranges from Lower to Middle Cenomanian, corresponding to *Rotalipora brotzeni* and the earliest part of the *Rotalipora cushmanni* zones. The *Mantelliceras mantelli* and *Acanthoceras rothomagense* ammonite zones were also identified in this unit.
2. Santa Fe carbonate breccias (Simó and Puigdefábregas, 1985). These represent platform and slope sediments redeposited as a breccia into marls. The breccia, which reaches 130 m in thickness, gradually grades-up into the next unit. The age of the Santa Fe breccia is late Middle-early Upper Cenomanian, containing planktonic foraminifera from the *Rotalipora cushmanni* zone and ammonoids from the *Calycoceras naviculare* zone.
3. Calcisphaerid limestones of the Pardina Fm (Caus *et al.*, 1993). Within this 80 m thick lithological unit, three subunits have been distinguished: a) Homogeneous calcisphaerid-rich packstones-wackestones with planktonic foraminifera from the *Rotalipora cushmanni* zone (Upper Cenomanian); b) Calcisphaerid wackestones-packstones with nodular black chert and synsedimentary contoured beds with milimetric-scale lamination. The only planktonic foraminifera present are hedbergellids, heterohellicids and witheinellids. Because of the absence of *Rotalipora cushmanni* and the presence of large *Whiteinella* these sediments are considered as belonging to the W. *archaeocretacea* zone (uppermost Cenomanian – lowermostTuronian, from Bengton 1996); c) Calcisphaerid wackestones with planktonic foraminifera from the *Helvetoglobotruncana helvetica* and *Marginotruncana sigali* zones, which indicate a Turonian age. The Cenomanian-Turonian boundary is placed within unit b.

On the platform, the Cenomanian-Turonian interval is represented by two different units separated by a very sharp contact, which reflects a change in the sedimentation regime. The lower unit, the Santa Fe formation (Mey *et al.*, 1968), consists of very well-bedded mudstones, wackestones and, more rarely, packstones with alveolinids, miliolids, agglutinated foraminifera, gastropods and echinoderms, with occasional beds very rich in oysters. The high degree of bioturbation and the faunal content suggest that sedimentation took place in a broad, relatively flat, very shallow muddy platform. Some rudist and coral build-ups developed at the platform margin. The upper unit is represented by calcisphaerid wackestones-packstones very rich in echinoid debris mixed with scarce planktonic foraminifera from the *Helvetoglobotruncana helvetica* zone at its base, that grade-up into homogeneous calcisphaerid wackestones with planktonic foraminifera from the *Marginotruncana sigali* zone. The lithology and faunal content of the calcisphaerid sediments indicate deposition under open-marine conditions.

THE CENOMANIAN-TURONIAN BOUNDARY

Isotopic studies in both settings allowed us to establish a detailed correlation between the basin and platform facies. The basinal sediments corresponding to the *W. archaeocretacea* zone interval (middle part of the Pardina Fm) registered an excursion of ^{13}C. This isotopic anomaly can also be followed on the platform at the top of the Santa Fe Fm (fig. 1). Consequently, it exists a gap in the platform comprising at least the *W. archaeocretacea* zone.

The unusual amount of calcisphaeres (and perhaps other kind of nano- and picoplancton not preserved in the fossil record) in the open-marine sediments during the studied interval reveals intense primary productivity in the surface waters, which can be related to the relative richness of nutrients. This primary productivity was the responsible of the blackshale deposits and the extinction of keeled planktonic foraminifera.

In the shallow platform setting, the gap is interpreted as being caused by the arrival of the eutrophicated water during high sea-level, which would block the growth of extreme and moderate k-strategist carbonate producers. As a result of that, larger foraminifera, corals and/or molluscs would disappear abruptly. The abundance of echinoid fragments mixed with plankton in the lowermost part of the Pardina Fm would indicate the colonisation of the platform by r-strategists.

ACKNOWLEDGEMENTS

The work was partially supported by the Spanish "Ministerio de Ciencia y Tecnología" project: BTE2003-04101.

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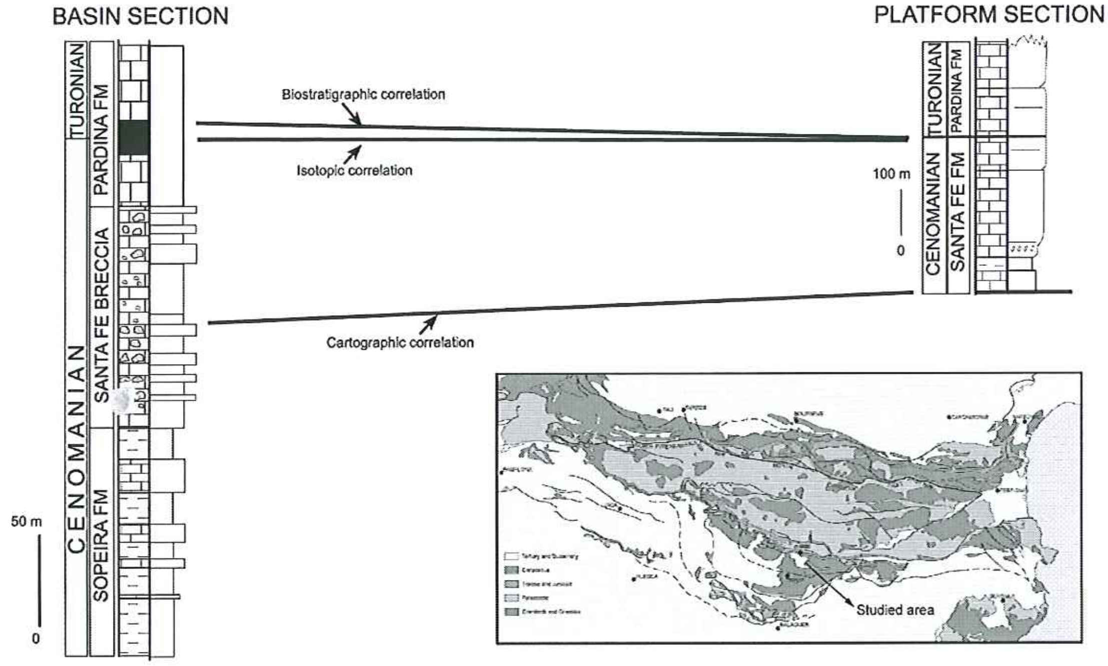

FIG. 1. Localisation of the studied zone, and basin-platform correlation.

Biogenic silica accumulation in relation to mid-Cretaceous Oceanic Anoxic Events. Correlations between tropical realms in Tethys, Atlantic and Pacific oceans

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Oceanic Anoxic Events (OAEs) represent intervals of organic matter enrichment in pelagic sequences, often preserved as black shales. They reflect periods of changes in global climate which affected ocean chemistry and productivity. Radiolarian biogenic silica is often abundant in black shale horizons (i.e. the Selli and Bonarelli levels in Italy) and together with other proxies is regarded as an additional argument in favour of the high productivity model for the generation of OAEs. This is essentially because radiolarian-rich sediments occur today under fertile water masses, in association with other high productivity indicators (i.e. diatoms, organic matter).

The spatial and temporal distribution of organic matter and biogenic silica provide valuable insights into the driving forces leading to Mid-Cretaceous OAEs (i.e. generalised anoxia vs. heightened productivity) and the extent to which some of these events (other than OAEs-1a and 2) were of truly global (as opposed to regional) significance. We here discuss results from an Aptian-Albian Tethyan section (the Sopoti section of the Ionian zone) and Cenomanian sediments recovered recently from the tropical Atlantic (Demerara Rise, Leg 207).

The Sopoti section is situated in the Mali Gjere mountain of Southern Albania. The monotonous sequence of the Lower Cretaceous micritic Vigla limestones is interrupted by two horizons rich in argillaceous and siliceous components:

(i) the lower horizon (*ca.* 8 meter-thick) is composed of beige marly limestones, greenish-blackish marls and black shales. Thinly bedded chert layers occur towards the top of this horizon. It is dated as latermost Barremian to early Aptian by means of radiolaria and calcareous nannofossils. Organic matter preserved in black shales ranges between 0.3 and 8.5% (mean value of TOC around 2.2%). Radiolaria may represent as much as 25% of visible elements in some siliceous levels (estimations made according to the semi-quantitative method of Baccelle & Bosellini 1966). This horizon is regarded as the equivalent of the Fourcade Level, defined recently in the Ionian zone of Greece (Danelian et al. 2002, 2004), which accumulated during OAE 1a;

(ii) the upper horizon is approximately 15 meter-thick and is composed of thinly-bedded marls, shales, limestones and cherts, with a prominent package of black shales occuring towards the top. In spite of the shaly and relatively dark grey/blackish aspect of numerous levels of this horizon, Rock-Eval analyses revealed no significant amounts of organic carbon (below detection level). Radiolaria are abundant throughout this horizon and semi-quantitative estimates suggest that they make up to 40-50% of the total rock in places. Integrated biostratigraphic data based on calcareous nannofossils, radiolaria and dinoflagellates indicate this horizon is latermost Aptian to early Albian in age. Therefore, given the occurrence of numerous black shale beds and its age straddling the Aptian/Albian boundary, this horizon is correlated with OAE-1b, in spite of the absence of any detectable organic matter in it. The expression of OAE-1b in the Ionian zone of Albania is unusual when compared with co-eval sections in Italy or south-east France, because of its relative paucity in terrigenous input (i.e. clays), enrichment in biogenic silica and absence of preserved organic matter. It is likely that the water-masses of the Ionian zone in southern Albania responded in the same way as the Pacific waters at Shatsky Rise, where in spite of increased productivity and biosiliceous accumulation during OEA-1b, black shale deposition did not occur, possibly because "the carbon-burial threshold" was not reached (Robinson et al. 2004).

The sedimentary expression of the OAE-1a and OAE-1b events in the Sopoti section reflects intervals of increased productivity and elevated biogenic silica flux in the Ionian zone of Albania. Therefore the abundance of radiolarian biogenic silica in the lower Aptian and uppermost Aptian-lower Albian sediments of the Sopoti section confirms the scenario for the formation of Large Igneous Provinces (Ontong Java and Kerguelen, respectively) as being at the origin of these two OAEs. Global warming due to massive volcanic activity would have as a consequence an accentuated hydrologic cycle and stronger wind-driven upwellings. Increased availability of volcanically-induced dissolved iron and other nutrients in the ocean would have fuelled marine productivity (Arthur et al. 1985; Jenkyns 1999; Larson & Erba 1999; Leckie et al. 2002).

Regarding younger anoxic events, it has been also suggested that OAE-2 was triggered by ocean fertilisation following mantle plume volcanism. This scenario is largely based on current evidence from some Tethyan sections from Apulian basins (i.e. the Bonarelli Level , which is rich in organic matter and radiolarian biogenic silica). However, the story seems to be quite different in the tropical Atlantic (offshore Surinam). Pelagic sediments, which were drilled on Demerara Rise (Leg 207) consist of finely laminated black shales for the Cenomanian to Santonian interval. These black shales accumulated, without any obvious interruption, for more than 15 Ma. We have investigated the radiolarian record throughout the interval which contains OAE-2, as it is delimited by the C-isotope curve (Erbacher et al., study in progress). Radiolaria, although sparse, occur frequently throughout the upper Cenomanian part of the Demerara black shales and are often well-preserved. Surprisingly, unlike the sedimentary record of some Tethyan basins, radiolarian abundance not only fails to pick up during the OAE-2 event, but with the exception of its initial phase, Radiolaria appear to be entirely absent in this interval.

Therefore, in the thick black-shale Atlantic sequences the possibility of an increase in radiolarian abundance in relation to OAEs is open to question. And the biogenic silica record of Demerara poses many challenges to biogeochemical models suggested for the OAE-2, involving either volcanically-induced iron fertilisation of oceans (as discussed above) or productivity increase driven by improved recycling of phosphorus following widespread anoxia (as recently suggested by Nederbragt *et al.* 2004).

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ENREGISTREMENTS DE L'EVENEMENT ANOXIQUE DU PASSAGE CENOMANIEN-TURONIEN CONTRAINT DANS UN CADRE TEPHROCHRONOLOGIQUE (BASSIN DU WESTERN INTERIOR)

Records of the Cenomanian-Turonian anoxic event constrained by volcanic ashes (Western Interior Basin)

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MOTS-CLES – Cénomanien-Turonien, bassin du Western Interior, bentonites, foraminifères planctoniques, isotopes stables, paléoenvironnements.

KEY WORDS. - Cenomanian-Turonian, Western Interior Basin, Bentonites, Planktic Foraminifera, stable isotopes, Paleoenvironments.

Au passage Cénomanien-Turonien cinq horizons de cendres volcaniques (A, B, C, D et E), formant des lignes isochrones indépendantes, sont corrélés à travers la majeure partie du bassin du Western Interior sur plusieurs millions de km^2. Le cadre chronostratigraphique est ainsi défini avec une haute résolution. Les signaux stratigraphiques classiquement utilisés (bio-, chimio-) pour établir des corrélations y sont intégrés afin de tester leur synchronisme, lors d'une période où la mise en place de l'événement anoxique OAE2 engendre de profondes perturbations avec l'extinction des rotalipores et une signature géochimique caractéristique. En outre, le bassin nord-américain est un cadre idéal de part sa configuration paléogéographique où les masses d'eau froide et téthysienne s'affrontaient dans un long couloir sub-méridien s'étendant du Canada jusqu'au Mexique.

Sur plusieurs centaines de kilomètres, sept coupes, dont le pivot internationalement connu de Pueblo (Colorado), sont de nouveau reprises suivant deux transversales : Arizona-Kansas et Colorado-Dakota du Sud.

Avec la dernière occurrence de *Rotalipora cushmani* sous le banc 86 (à la base duquel est positionnée la limite Cénomanien-Turonien par les ammonites, Fig.1) et la première occurrence de *Helvetoglobotruncana helvetica* reconnue en lame mince au sein de ce dernier, la distribution des foraminifères planctoniques à Pueblo souligne une réduction drastique de la zone d'extension partielle à *Whiteinella archaeocretacea.* Les données biostratigraphiques couplées au suivi latéral des bentonites démontrent le diachronisme à l'échelle régionale des occurrences des espèces-index *R. cushmani* et *H. helvetica* et, par suite, la variabilité de l'écozone à *W. archaeocretacea* qui a donc une faible valeur temporelle. Cette variabilité doit correspondre à une réponse des foraminifères aux fluctuations paléocéanographiques locales et/ou à un biais d'enregistrement lié à la raréfaction des espèces-index spécialisées, dans la tranche d'eau, suite au renforcement de l'anoxie.

L'analyse de la microfaune planctonique révèle qu'aux côtés des formes carénées *R. cushmani* et *R. greenhornensis,* existent des formes à ouvertures suturales secondaires sur la face ombilicale mais chez lesquelles la carène est atrophiée ou absente (morphotypes globuleux) appartenant au genre *Anaticinella* par Eicher en 1972. La première espèce, *Anaticinella multiloculata* présente un grand nombre de loges sur le dernier tour de spire (6,5 à 9). La seconde, *Anaticinella planoconvexa* possède moins de loges que la précédente ; ces formes dériveraient respectivement de *R. greenhornensis* et *R. cushmani* par atrophie de la carène (Eicher, 1972 ; Longoria, 1973 ; Leckie, 1985).

Sur quelques dizaines de milliers d'années *A. multiloculata* va prendre le pas sur les rotalipores. Cet événement observé à Pueblo et à Las Animas sous le banc 63 (Fig.1), durant lequel apparaît et prolifère *A. multiloculata* (dans la zone d'ammonite à *G. mosbyense*), semble synchrone à l'échelle régionale. Pour les rotalipores, aucune relation systématique évidente ne semble rattacher l'évolution quantitative des deux espèces *cushmani* et *greenhornensis* à celle des microfaciès, témoins de l'environnement de dépôt. Les anaticinelles sont préférentiellement observées lors des intervalles hypoxiques à anoxiques et l'événement à *A. multiloculata* est contemporain de passées plus hypoxiques (Fig.1). Ainsi, en réponse à la diminution du taux d'oxygène dissous, les anaticinelles, par l'atrophie de la carène que possèdent leurs ancêtres les rotalipores, pourraient acquérir la possibilité de rester dans les eaux de surface moins touchées par l'anoxie. L'absence de carène présenterait par suite un avantage sélectif. Néanmoins celui-ci n'a pas suffi aux anaticinelles pour survivre aux modifications de plus en plus drastiques du milieu océanique puisque le genre *Anaticinella* va disparaître de manière synchrone à son ancêtre *Rotalipora* (i.e. *R. greenhornensis* et *A. multiloculata* sous la bentonite A ; *R. cushmani* et *A. planoconvexa* sous le banc 86 à Pueblo, Fig.1).

Plus au nord (Dakota du Sud), nos corrélations indiquent que des formes de transition entre *Whiteinella praehelvetica* et *H. helvetica* apparaissent dès le Cénomanien terminal. Alors que les premières loges sont globuleuses, les deux ou trois dernières loges du dernier tour présentent une carène. Taxonomiquement, l'attribution certaine à l'espèce est délicate en raison du continuum entre *W. praehelvetica* et *H. helvetica*. Stratigraphiquement, ces formes apparaissent paradoxalement lors de l'acmé de l'événement anoxique océanique alors que l'apparition d'une carène semble habituellement liée à des environnements plus oxygénés.

Intégrés dans ce cadre chronostratigraphique à haute résolution, les courbes du $\delta^{13}C_{carb}$ acquises à Pueblo, à Lohali Point (Arizona), à Elm (Kansas) et à Hot Springs (Dakota du Sud) montrent que l'excursion isotopique du carbone est synchrone avec une signature uniforme à l'échelle du bassin ; les différences observées dans le motif isotopique témoignent de hiatus dans l'enregistrement sédimentaire. Trois événements isotopiques principaux, déjà observés par Pratt et Threlkeld (1984), se succèdent. Le premier avec un brusque accroissement du $\delta^{13}C_{carb}$, se positionne sous la bentonite A à la base de la zone d'ammonites à *S. gracile*. Le deuxième, entre les bancs 67 et 77, montre un retour vers des valeurs plus basses. Enfin, le troisième débute au-dessus du banc 77 au sommet de la zone à *S. gracile*. Il est marqué par un retour à des valeurs élevées qui se maintiennent jusqu'à la bentonite C.

A l'échelle mondiale, trois événements isotopiques sont classiquement enregistrés dans d'autres domaines paléogéographiques que ce soit à Wünstorf dans le bassin de Basse-Saxe (Ferry *et al.*, 1995), à Eastbourne dans le bassin anglo-parisien (Paul *et al.*, 1999) ou encore à Pont d'Issole dans le bassin vocontien (Morel, 1998 ; Grosheny et al., sous presse). Cependant, s'il est tentant de vouloir les corréler aux trois événements enregistrés dans le bassin du Western Interior, à Pueblo, l'absence de lignes isochrones indépendantes des fluctuations environnementales, telles que les niveaux de bentonites, entre ces différents domaines paléogéographiques rend cette hypothèse incertaine. En effet, les corréler suppose que ces modifications géochimiques sont synchrones. Le fait que les signaux isotopiques et biologiques coïncident est souvent considéré comme preuve de ce synchronisme. Néanmoins, les mêmes modifications environnementales, décalées dans le temps, pourraient être la cause d'enregistrements semblables.

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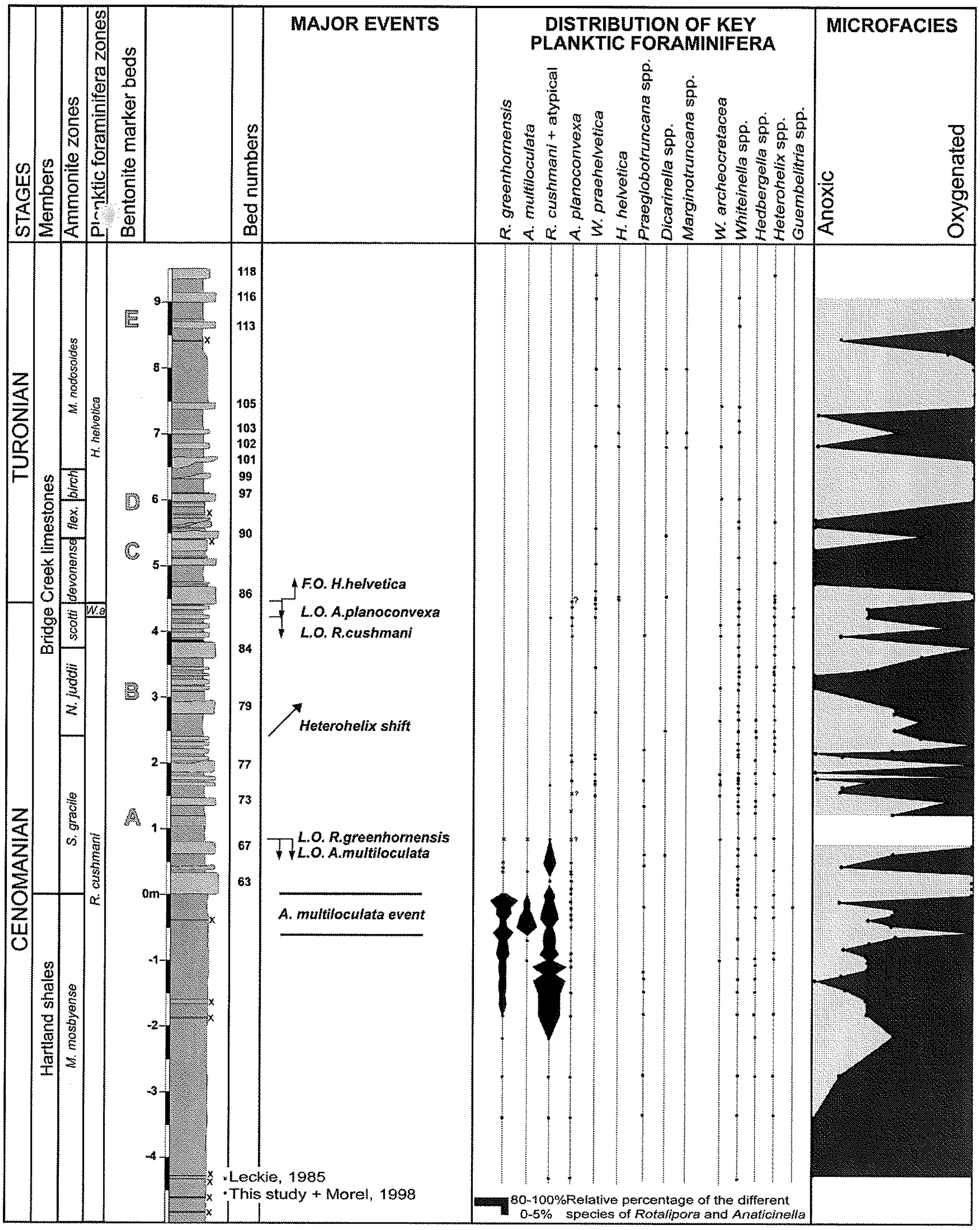

Fig.1: Distribution des principales espèces de foraminifères planctoniques et des microfaciès de la coupe de Pueblo (Colorado). D'après Desmares et al. (2003)

MICROPALEONTOLOGY OF THE BARREMO-APTIAN DEPOSITS OF JABAL MSELLA IN NORTH-EASTERN TUNISIA

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The Jabal Msella outcrop is located in the Grombalia map (1/25 000) to the south of Tunis. The study sediments are 310 m-thick and are divided into three units.

The first unit which is 50 m-thick, is composed of successions of marl and limestone beds. The limestone beds are 1 m-thick each and are predominant. This unit yield abundant benthic foraminifers, such as *Ammodiscus tenuissimus*, *Dentalina communis*, *Lenticulina ouachensis*, *Nodosaria paupercula*, etc., and fewer planctonic foraminifers such as *Praehedbergellidae.*

The second unit is 35 m-thick and is mainly composed of marls including some very thin limestone beds. This unit yields abundant belemnites and ammonites. The topmost of this series is a limestone beds made up by laminated plates. The microfauna association is composed essentially of benthonic foraminifers: *Dentalina oligostega*, *D. paupercula*, *Gavelinella barremiana*, *Lenticulina* (*L*) *ouachensis*, and rare planctonic foraminifers such as *Gorbatchikella kugleri* and the ammonites *Barremites goeux* and *Mesohibolites* sp.

The third unit which is the thickest (220 m), is made up by greyish marls including fewer yellowish thin limestone beds. The marl levels contain rare foraminifers benthonic, however the planctonic community becomes abundant and varied, *e.g.*: *Blowiella blowi, B. gottisi, B. duboisi, Lilliputianella bizonae, L. globulifera, Globigerinelloide ferreolensis G. algerianus*, and *H. trochoidea.*

Owing to the foraminifer associations, the first unit is attributable to a probable age of Hautherivian-Barremian *p.p.*, whereas, the second unit is exclusively Barremian of age, and the third unit is attributed to the Aptian.

The biostratigraphic study of Jabal Msella successions permit to recognize benthonic and planctonic foraminifer biozones.

Subalpine Aptian-Albian deposits (SE France) Time and space integrated multidisciplinary approach.

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The SE-France basin, located on the Northern margin of the Tethyan Ocean, (fig. 1) represents, at the Aptian – Albian period, a rare, well-exposed field analogue of present-day passive margins. Multidisciplinary stratigraphic approaches have been used combining facies analysis, multi-groups biostratigraphy, radiometric datations, and depositional sequences identification in order to reconstruct the evolution and the dynamic of the basin (fig. 2). Thus this stratigraphic database, based on fifty log sections, has been completed with data from other basins located in the tethyan (Ombria-Marche basin, Italy) and boreal realms (Hannover basin, Germany).

At this time, the SE-France basin is characterized by well-developped silicoclastic sedimentation (fig. 2). To reconstitute the dynamic of this sedimentary complex, we have firstly constrained the physiography of the basin in comparison with the location and the evolution of the shelf break, and the characterisation of large slump scars and submarine canyons (large-scale erosional features *sensu* Normark et al., Rewiews of Geophysics 31 (1993) 91-116). On this paleomargin, the slope sedimentation can be represented up to 90% by slumps, debris flow deposits, turbidites and massive sands interbedded in the marly background.
Then, the basin deformation, related to tectonic and/or gravity (salt, mud diapirisms), has been investigated (fig. 3) to underscore the mechanisms controlling the sea-bottom geometry and to explain the successive depot-centres location (Rubino, 1989; Friès & Parize, 2003).
The sequential analysis (*sensu* Vail et al., 1991 and Posamentier & Allen, 1999) of the sedimentary bodies using the new biostratigraphic framework has been made and leads to a synthetic 3D dynamic schema of the apto-albian silicoclastic deposits of a continental margin from the shelf to the basin.

Started 20 years ago, the integrated stratigraphic database, based on the culture of our research institutions, remains still in progress. From our field-based knowledge, it is possible :
(1) To characterize the spatio-temporal organization of sedimentary bodies along platform-slope-basin transects, and to discuss the evolution of turbiditic systems,
(2) To provide a relative and absolute chronostratigraphy using orbital forcing (Milankovitch cyclicities) and K-rich minerals (glauconite, sanidine, mica) for each depositional sequence (Fiet et al. this meeting),
(3) To propose synthetic models on the evolution of faunas and flora (planktonic foraminifers, ammonites, dinokystes, spores and pollens), correlations between, tethyan and boreal associations (ammonites, dinokystes),
(4) To quantify the diachronism of first and last occurrences of biostratigraphic taxa,
(5) To propose a reference $\delta^{13}C$ - $\delta^{18}O$ curve sampled each 100 000 years from the Barremian to the lower Cenomanian (nearly 23 My)

This original integrated approach must go on from new collaborations and complementary expertises. By the quality and continuity of the outcrops, the Aptian-Albian successions of the SE of France basin seem to be an exceptional field for a multidisciplinary, predictive and exportable approach.

Figure 1 – SE France Basin: palaeogeographical reconstruction at Uppermost Aptian time (From Friès & Parize, 2003).

This basin represents a well-preserved segment of the northern margin of the cretaceous tethyan Ocean. The shelf and the upper slope deposits crop out with excellent conditions. In addition, Stratotypes of few substages and a golden spike (Albian-Cenomanian boundary) are located in this area.

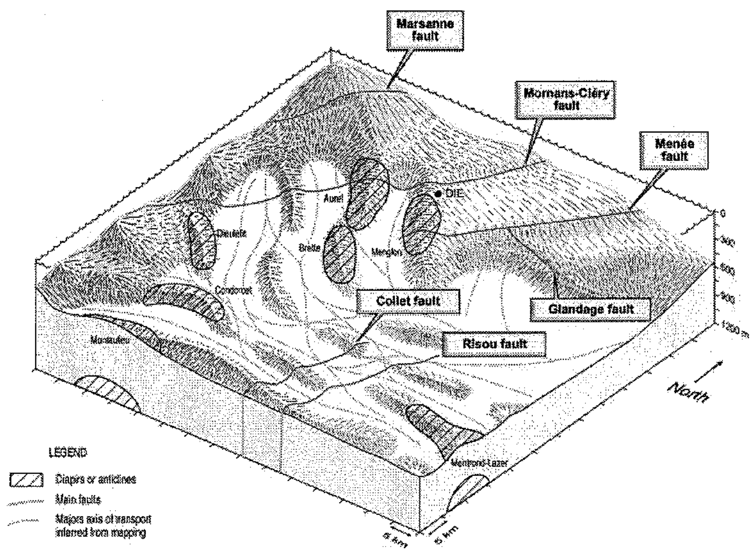

Figure 3 – Upper slope area of Vocontian palaeomargin : 3D palaeogeographic reconstruction at Uppermost Aptian time (From Friès & Parize, 2003).

This physiographic organisation is mainly reported to early halokinesis. The stratigraphic pattern of the upper slope deposition is constrained by this confined setting, e.g. all turbiditic systems are channeled from their source to their distal part.

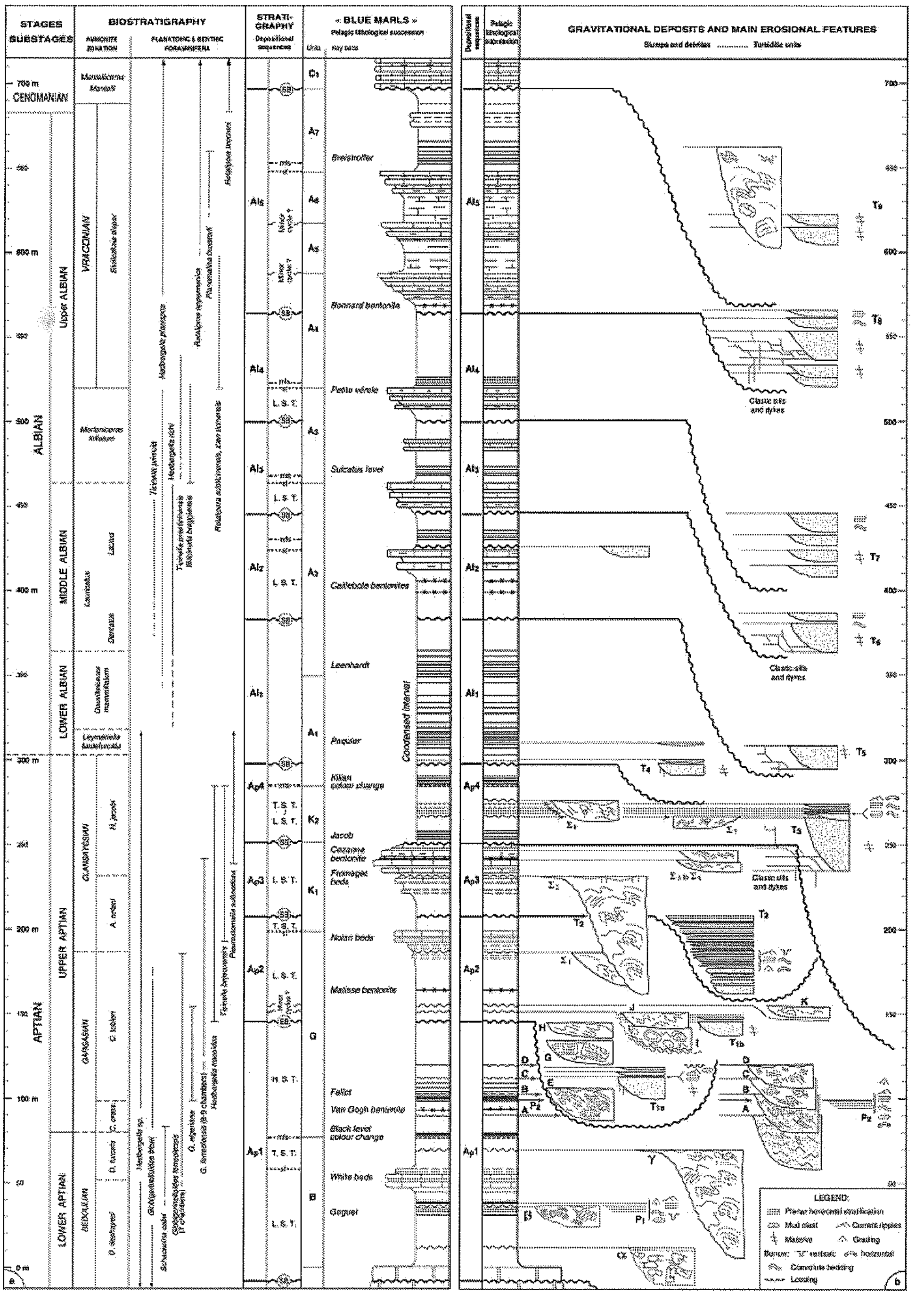

Figure 2 – Litho-, bio- and chronostratigraphic organisation of Apto-Albian Vocontian slope deposits (Parize *et al.*, 2003).

The biostratigraphic column is being revised (Determinations of the ammonites by L.G. Bulot and J-L. Latil; publications in press). Collected on platform, the glauconites (without thick burial and diagenetic alteration) provide elements of absolute dating (Fiet *et al.*, this meeting).

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La crise Aptienne en Tunisie
L'exemple du Jebel EL HAMRA

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L'analyse cartographique et structurale du Jebel EL HAMRA à l'Ouest de Kasserine (Tunisie centro-occidentale) confirme l'existence d'une structuration fini-aptienne en Tunisie.

Sur le plan, lithostratigraphique, la série aptienne, où dominent ici les dolomies rousses en bancs plus ou moins épais (formation Serj) est surmontée par la série marneuse de l'Albien (formation Fahdène) elle même coiffée par les barres carbonatées cénomano-turoniennes. Cependant, entre la masse dolomitique aptienne qui constitue d'ailleurs l'ossature du jebel El Ḥamra et les marnes albiennes présentes sur les flancs du jebel s'intercale une série marno-calcaire (membre supérieur de la formation Serj de M'Rabet) encadrée par deux discontinuités majeures D et D' qui présentent toutes deux des indices d'émersion.

Sur le plan cartographique et structural, le Jebel El Hamra se présente aujourd'hui comme une succession subméridienne (N 20-30) de quatre blocs faillés et plissés, constitués de matériel aptien, drapés par une enveloppe à dominante marneuse albo-cénomanienne. Chaque bloc est défini et limité par deux familles de failles: l'une directionnelle N20-30 par rapport à l'axe du pli et sub-verticale, l'autre transverse et à fort pendage Nord. Les failles de cette dernière présentent une cinématique en faille normale et les premières également normales montrent un rejet souvent très faible à cause d'une forte composante décrochante dextre (flanc Ouest) ou sénestre (flanc Est). Il en résulte une direction d'extension orientée globalement NE-SW d'âge fini aptien car toutes les failles sont scellées cartographiquement par les premiers dépôts marneux de l'Albien. Plus précisément, sur le réseau directionnel nous observons systématiquement un dispositif géométrique et mécanique de flexure faille avec une rupture fragile des dolomies de la formation Serj et une déformation ductile des alternances marno-calcaires comprises entre D et D'. Cette dernière discontinuité aurait donc pour nous une signification tectonique et daterait par conséquent cette phase d'extension avec plus de précision. Par contre, la discontinuité D serait d'origine eustatique. Age et direction d'extension sont tout à fait conformes à la phase extensive régionale décrite et mise en évidence par de nombreux auteurs qui relient depuis longtemps cette crise à l'ouverture de l'Atlantique équatorial.

Enfin, l'absence cartographique de toutes les formations antérieures à l'Aptien, l'existence d'un cénomanien discordant sur le Trias immédiatement au Nord du Jebel El Hamra permet de proposer l'existence d'une zone positive d'origine diapirique à la même époque au Nord et peut être à l'Est de ce secteur comme cela a été prouvé au même moment dans d'autres régions de Tunisie.

Dans ces conditions, les blocs faillés du jebel El Hamra, à géométrie complexe dans le détail pourraient résulter de l'action combinée d'un phénomène géodynamique global (Extension NE-SW africaine) et d'un mouvement vertical, probablement linéaire (dôme ou mur de sel subméridien) et régional du bassin tunisien.

Radiolarian and foraminiferal events at the of Albian-Cenomanian and Cenomanian-Turonian boundaries (Tethyan province, Crimean Mountains, Ukraine)

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The Albian-Cenomanian and Cenomanian-Turonian boundaries in the Peritethyan province are associated with notable tectonic reconstructions, formation of a new system of rift basins, accompanied by active volcanic activity and a sharp change of oceanography and direction of paleocurrents. All these abiotic events affected the evolutionary trends of biota, radiolarians in particular, that, unlike forams, are well represented in the sections, including the intervals, which conform to oxigen-free events and, therefore, can be used for biostratigraphic purposes.

Well-known is the late Albian radiolarian assemblage of upper Albian clays, situated in the southeastern outskirts of the Simferopol city (Practical..., 1999). It is mostly represented by discoidal forms (Orbiculiforma multangula Pessagno, O. nevadaensis Pessagno, O. impressa (Lipman), Crucella crux (Lipman), Hexapyramix pantanelli Squinabol, Cenidiscus cenomanicus Aliev). Nassellaria (Cyrtoidaea) in the assemblage are scarce, though they posess a high stratigraphic resolution ability. Those are characterstic Albian species of Dictyomitra kanakhendensis Aliev, Crolanium cuneatum (Smirnova et Aliev). Virtually, all these species became extinct at the end of the Albian.

The radiolarian assemblage from the Cenomanian-Turonian boundary sequences of the section of Sel-Buchra and Belaya mountains (the Crimea) is also of great interest (Alekseev et al., 1997; Bragina, 2001, 2004; Naydin, Alekseev, 1980; Vishnevskaya, Kazintsova, 1990; Vishnevskaya, Sedaeva, 1987). A diverse radiolarian assemblage was recovered from the siliceous marls of the Upper Cenomanian section in Sel-Buchra Mountain. The section comprises the following characteristic species: Archaeocenosphaera ? melifera O'Dogherty (widespread in the Albian--early Turonian), Pyramispongia glascockensis Pessagno (middle Cenomanian--early Turonian), Orbiculiforma cachensis Pessagno (Middle Cenomanian), Diacanthocapsa euganea (Squinabol) (Middle--Late Cenomanian), Pseudoeucyrtis pulchra (Squinabol) (widespread in the Late Cenomanian--Early Turonian), Pseudodictyomitra pseudomacrocephala (Squinabol) (widespread in the Late Albian--Early Turonian), Hemicryptocapsa barbui Dumitrica (Aptian--Cenomanian), Xitus spicularius (Aliev) (Valanginian--Cenomanian), Sethocapsa orca Foreman (Valanginian--Cenomanian), Sethocapsa simplex Taketani (Albian-Cenomanian), Cryptamphorella conara Foreman, Hiscocapsa asseni (Tan) (Aptian-Cenomanian), and lots of other species (Fig. 1). A major part of these species, as can be inferred from the age intervals of existence, given in brackets, die out without passing the anoxic event.

Radiolarians are less abundant in the Aksu-Dere section (the Crimea) in the Cenomanian and, like carbonate plankton, are essentially represented by small inhibited species (conspicuous are abundant small planktonic Hedbergella, similar to radiolarians in size, and abnormal species of the Genus Rotalipora). Along with siliceous radiolarians, there are lots of spicules of siliceous sponges, often lacking a strict geometric configuration, which evidently show the salinity disturbance in the sedimentation basin.

Ferruginous covers of many shells or skeletal pyritization most likely suggest the reducing environment and rapid burial under shallow depths.

Radiolarians are for the most part represented by ordinary discs or primitive forms of Genus Dictyomitra. The assemblage was found to contain the following species: Anachoreta sagitta O'Dogherty (widespread in the Late Albian-Early Cenomanian), Holocryptocanium geysersensis Pessagno (widespread in the Late Albian-Early Cenomanian), Dictyomitra crassispina (Squinabol) (widespread in the Late Cenomanian), D. crebrisulcata (Sq.), D. turritum (Sq.), Godia lenticulata Jud (Albian-Cenomanian), Amphipyndax stocki (Campbell and Clark) (widespread in the Cretaceous, essentially in the Late Cretaceous) and many other, more widely distributed species.

An inhibited assemblage with occasional discs and spheras was recorded in the Belaya River section, which was found to contain Mallanites ? triquetrum (Sq.) (Late Albian-Cenomanian) Patellula cf. planoconvexa Pessagno (Cenomanian-Turonian), Squinabollum fossile (Sq.) (Albian-Cenomanian), Praeconocaryomma californiaensis Pessagno, P. lipmanae Pessagno (widespread in the Late Cenomanian-Early Senonian), Amphipyndax stocki (Campbell and Clark) (widespread in the Cretaceous, essentially in the Late Cretaceous), and many other, more widely spread species.

A more diverse Early Turonian radiolarian assemblage, derived from the same sections in the Crimea, includes the following characteristic species: Alievium superbum (Squinabol), Cavaspongia antelopensis Pessagno (widespread in the Early Turonian in California and in the Late Cenomanian--Early Turonin in the Mediterranean

Region), C. euganea (Squinabol) (widespread in the Late Albian-Early Turonian), Crucella cachensis Pessagno (widespread in the Late Cenomanian-Coniacian of the Russian Plate, and California and in the Early Turonian of the Mediterranean Region), C. irwini (widespread in the Late Turonian--Coniacian of California, Cenomanian--Early Turonian of the Mediterranean Region), Dumitricaia maxwellensis Pessagno (widespread in the Late Cenomanian--Early Turonian), Praeconocaryomma lipmanae Pessagno (widespread in the Late Cenomanian--Turonian), Dactyliosphaera lepta (Foreman) (widespread in the Late Albian-Cenomanian) Sciadiocapsa ? eyganea Squinabol (widespread in the Early Turonian), as well as species marked down the section: Archaeocenosphaera ? melifera O'Dogherty (widespread in the Late Albian--Early Turonian) Pyramispongia glascockensis Pessagno (Middle Cenomanian--Early Senonian), Pseudodictyomitra pseudomacrocephala (Squinabol) (widespread in the Late Albian-Early Turonian), Amphipyndax stocki (Campbell and Clark) (widespread in the Cretaceous, mostly Late Cretaceous), and many other spacies (Fig. 1). Along with the species, appeared in the assemblage in the Early Turonian (after the anoxic event), lots of species that experienced the oxygen-free event, still exist.

Thus, the anoxic event has not influenced the Cenomanian-Turonian radiolarian assemblages of the Crimea so greatly as it did the foraminiferal communities, which completely altered or renovated their composition. Radiolarian assemblages from the Albian-Turonian of the Crimea compare well with coeval assemblages of Italy, Spain, Turkey (Bragina, 2004; O'Dogherty, 1994; Salvini, Marcucci Passerini, 1998) and can be used not only as a stratigraphic datum, but are also good indicators of the paleogeographic conditions.

The morphological diversity and taxonomic composition of radiolarian and associations in late Cenomanian-early Turonian strata of Crimea Mountains are high, while foraminiferal are very poor. The domination of spheroidal and discoidal radiolarian groups is characteristic of the Albian and Cenomanian, while burst of all radiolarian morphological groups is observed in Turonian time.

The work was supported by the Program of the Presidium of the Russian Academy of Sciences "Origin and Evolution of Biosphere" and by the Russian Foundation for Basic Research projects 04-05-64503, 03-05-64425.

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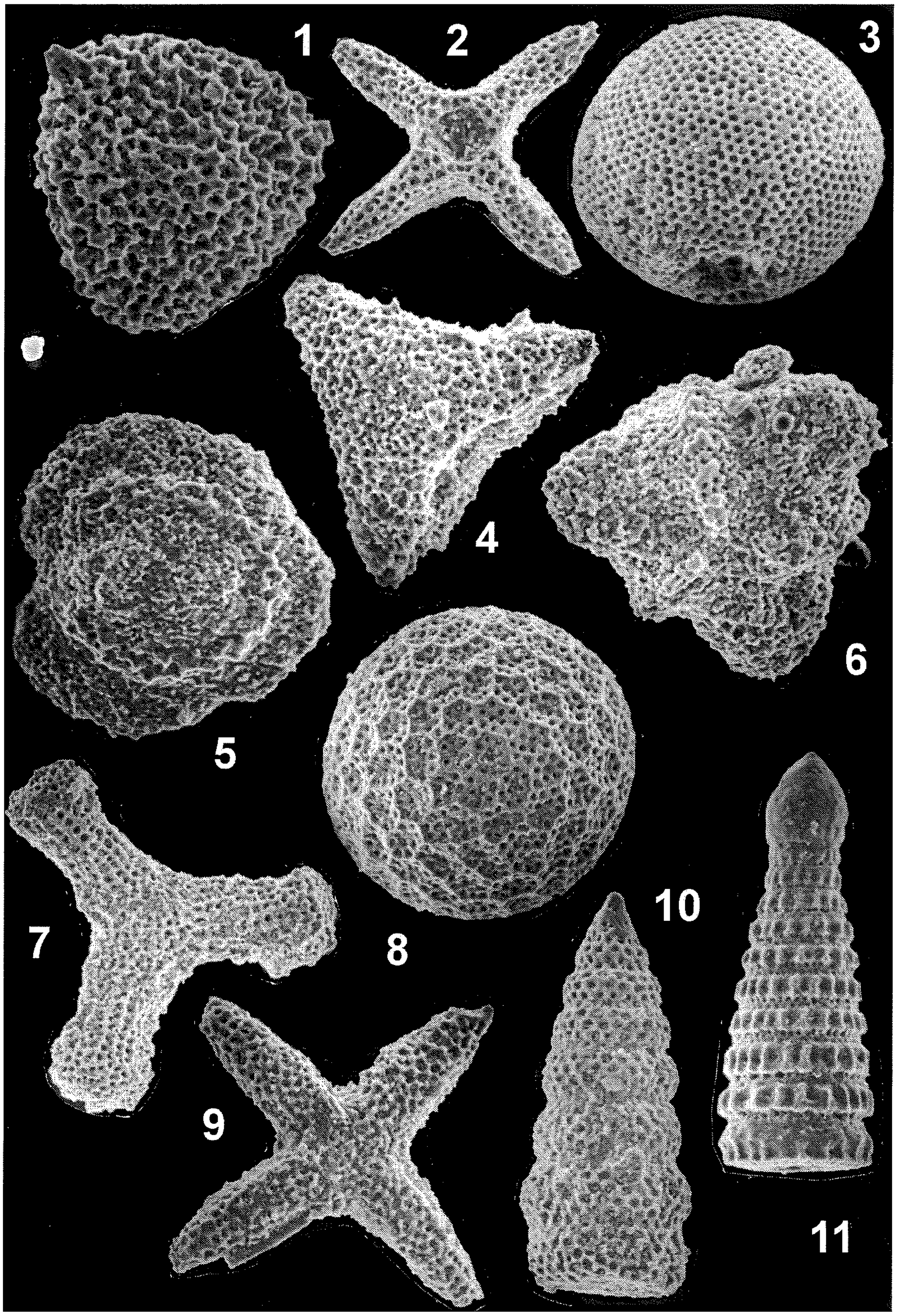

Fig. 1. Turonian radiolarians. 1 - Alievium sculptus (Squinabol), 2 – Crucella cachensis Pessagno, 3 - Hemicryptocapsa barbui Dumitrica, 4 - Cavaspongia antelopensis Pessagno, 5 – Godia sp., 6 - Pyramispongia glascockensis Pessagno, 7 – Patulibrachium sp., 8 - Archaeocenosphaera ? melifera O'Dogherty, 9 – Crucella messinae Pessagno, 10 – Stichomitra communis Squinabol, 11 - Pseudodictyomitra pseudomacrocephala (Squinabol). Magnification in Figs. 1-2 - in 200 times

From dysoxic to oxic conditions on the Levant carbonate platform: CTBE (OAE II) in Jordan

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Dysoxic sedimentation during the Mid-Cenomanian through lower Turonian is represented by an extended succession of greenish to dark-grey marls and clays on the Levant platform (Tethys southern margin). Starting in the mid-Cenomanian *rhotomagense* ammonite biozone, probably linkable to the "Mid-Cenomanian Event", dysoxic sedimentation is interrupted only by a short interval of intra-platform carbonate deposits, and continues into the lower Turonian. During the Cenomanian-Turonian Boundary Event (CTBE) there were apparently three main phases of dysoxic sedimentation. Between the first and second phase the intra-platform basin investigated here experienced a period of distinct cyclicity between clays/marls and reddish-beige, platy, highly bituminous limestones. This alternation most likely reflects the change between circulated and stangnant conditions caused by orbitally-forced climate variability. We focus on this interval at different palaeo-bathymetrical positions and find very variable types of the marl/clay deposits ranging from black shales in the deeper basin parts to marine red beds near presumed swell regions. This feature of the Levant Platform sedimentation can be compared to some of the epicontinental basins of the Boreal Realm (e.g. NW-Germany) where a bathymetry-dependent oxygen distribution is observed, too. The Cenomanian-Turonian sequence of dysoxic sediments in Jordan is terminated by a gradual switch into reddish marls indicating highly oxic conditions for a short period of time. This change occurs in conjunction to a globally observed general, although diachronous, onset of oceanic red beds following the Oceanic Anoxic Event II.

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